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# First Lunar Outpost Support Study

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# **First Lunar Outpost**

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## Section 1                      Project Development

The First Lunar Outpost (FLO) is the first manned step in the accomplishment of the Space Exploration Initiative, Vice President Bush's directive to NASA on the 20th anniversary of the Apollo moon landing. FLO's broad objectives are the establishment of a permanent human presence on the moon, supporting the utilization of extraterrestrial resources in a long-term, sustained program. The primary objective is to emplace and validate the first elements of a man tended outpost on the lunar surface to provide the basis for: (1) establishing, maintaining and expanding human activities and influence across the surface; (2) establishing, maintaining and enhancing human safety and productivity; (3) accommodating space transportation operations to and from the surface; (4) accommodating production of scientific information; (5) exploiting in-situ resources. Secondary objectives are: (1) to conduct local, small scale science (including life science); (2) In-situ resource utilization (ISRU) demonstrations; (3) engineering and operations tests; (4) to characterize the local environment; (5) to explore locally. <sup>1</sup>.

The current work is part of ongoing research at the Sasakawa International Center for Space Architecture supporting NASA's First Lunar Outpost initiative. Research at SICA supporting the First Lunar Outpost initiative has been funded through the Space Exploration Initiatives office at Johnson Space Center.

Initial research at SICA from 1990 to 1991 focused on the design of a habitat module supporting FLO operations. The development was constrained by parameters of the habitat shell, developed to utilize a modified Space Station module, 15' in diameter by 44' in length. The configuration was to support six (6) crew members for a 45 day period, and focused on habitability issues, as well as aesthetic and functional quality. The design was mocked up on the University of Houston campus in 1991, supported through funding by Grumman, NASA, and the University of Houston, and currently serves as a design evaluation and research facility.

A secondary habitat study was begun in early 1992, developed from shell constraints of the utilization of a modified half Space Station module, 15' in diameter by 22' in length. The mission profile was modified to support four (4) crew members for a 45 day period, therefore, volumetric and functional issues were of critical importance in this study. A volumetric analysis of supported activities developed guidelines for functional volumes, which were then developed to conceptual solutions. The initial phase of this study was completed in May of 1992.

The objectives of the current study are to further develop a module concept from an evaluation of volumetric and programmatic requirements, and pursue a high fidelity design of this concept, with the intention of providing a high fidelity design mockup to research planetary design issues and evaluate future design concepts.

## **Section 2                      Research Objectives**

- **Provide a volumetric and programmatic evaluation to determine minimum requirements to support initial lunar habitation, while providing for later lunar development stages, in support of First Lunar Outpost initiatives.**
- **Provide program objectives within the range of NASA's capabilities, scheduling, and projected funding.**
- **Whenever possible, provide for the utilization of off the shelf technologies in program development and mission planning to control program and mission costs.**
- **Promote the development of technologies required to support permanent lunar habitation.**
- **Promote the involvement of the commercial sector in the exploration and development of space.**
- **Develop realistic and obtainable solutions to First Lunar Outpost initiatives.**

## Section 3                      Scope Of Research

- The evaluation of volumetric and programmatic requirements of initial lunar habitation in support of First Lunar Outpost initiatives.
- The high fidelity design development of the habitat module supporting First Lunar Outpost operations.
- The research of supporting design issues:
  - Radiation protection
  - Environmental Control and Life Support Systems (ECLSS)
  - Storm shelter operations
  - Logistics operations
  - Extra-Vehicular Activity (EVA) requirements
  - Intra-Vehicular Activity (IVA) requirements
- Mission planning, launch modes, and transfer vehicle operations are considered to be beyond the scope of this study, therefore are developed from First Lunar Outpost directives and guidelines supported by the Planet Surface Systems Office at Johnson Space Center.

## **Section 4                      FLO Mission Profile**

### **General**

45 day mission (Lunar Day/Night/Day)

Split mission profile flown in two (2) launches.

4 person crew (Design constraints supporting an anthropomorphic range from 95th percentile North American male to 5th percentile Asian female).

### **Emplacement**

Emplacement goals of the mission are to land and deploy the initial elements of a lunar outpost capable of sustaining human life. The emplacement mission will be an automated landing at a pre-selected site, assuming no previous surface infrastructure. Site criteria are to support First Lunar Outpost initiatives.

### **Candidate Mission Sites**

FLO reference site is located in the Mare Smythii at 1.7°N, 85.8°E, which is within the eastern limb region near the lunar equator. <sup>2</sup>

### **Initial Launch**

Descent stage lands FLO habitat on surface, equipped with ambient Consumables for a seven (7) day contingency period. The habitat is to remain on the lander, therefore no off loading or regolith shielding is required. Habitat power and communications systems deployed and habitat module is powered up.

Habitat subsystem operational status verified remotely by ground control during Remote Operational Readiness Inspection, prior to manned launch.

## Section 4 FLO Mission Profile

### Secondary Launch

Descent stage lands 4 crew members, crew ascent module, logistics module, and unpressurized lunar rover. Lunar landing to occur around lunar dawn to accomplish lunar day/ night/ day cycle. Lunar landing to occur within specified EVA walking distance, approximately 1 km. from initial landing.

The crew will perform an EVA to collect contingency samples, and deploy selected scientific experiments. The crew will obtain operational verification of the habitat prior to transfer operations.

Crew transfer operations will involve off loading of the lunar rover and logistics module, crew transfer, emplacement, and checkout. The rover will be capable of transferring 4 crew members and the logistics module in one operation. The crew and logistics module will transfer to the habitat module.

Upon arrival, the crew will complete any unfinished outpost emplacement, deployment, activation and checkout procedures, and perform an Operational Readiness Inspection (ORI) <sup>3</sup> prior to habitat occupancy. The logistics module will be attached to the habitat module, using a mechanical assistance device. Mechanical assistance devices considered are electric winch and pulley systems, and robotic arm systems. EPS systems transfer to the logistics module will be performed, allowing powering of the logistics module through the habitat EPS systems. The module will be configured for Manned Mission Mode during mission operations.

### Crew Departure

Upon mission completion, around the second lunar sunset, the crew will configure the habitat for Unmanned Mission Mode and the outpost for their departure, transfer to the crew vehicle with any return cargo and initiate the crew return to Earth. The habitat will be remotely transferred to Storage Mode after departure.

## Section 5                      Mission Assumptions

### 5.1        Mission Operations

The FLO habitat is to support 4 crew members for a 45 day (lunar day/ night/ day) mission.

The emplacement mission (habitat and descent stage) will be an automated landing at a pre-selected site, assuming no previous surface infrastructure. The habitat module is to remain on the lander, therefore no off-loading or shielding operations are required.

The habitat module and crew ascent stage will utilize a common descent stage for redundancy of hardware and a reduction of development costs. <sup>4</sup> The mission is to be developed with a maximum level of modularity and hardware adaptability, to provide program longevity and mission flexibility. Modularity of mission components will provide for hardware reconfiguration, maintenance and replacement. Use of off the shelf technologies whenever feasible is considered critical in achieving obtainable program and mission costs, and provides a degree of insurability in the utilization of flight tested subsystems.

The nominal mission should support future outpost mission objectives, and must be adaptive in programmatic and hardware development strategies to provide mission operational flexibility.

### 5.2        Logistics

A pressurized, thermally controlled logistics module is to provide for resupply operations. The logistics module is to land with the crew ascent stage and transferred to the habitat module utilizing an unpressurized rover.

The logistics module is to be attached to the habitat module to provide access from within the habitat module.

The logistics module will serve as a supply and storage container during mission operations. The module will be supplied with rack storage drawers that will be exchanged with storage drawers in the logistics module. Waste containers will be exchanged during resupply operations, and stowed in the logistics module.

The logistics module is ideally returned to an LEO node with the crew return vehicle for resupply operations in future lunar outpost operations. If operational costs prove to be prohibitive, the logistics module may be detached and remain on the lunar surface. A reutilization of the module in future lunar outpost operations is desirable.



## Section 5                      Mission Assumptions

### 5.3        Consumables

Mission consumables are provided in the following areas

- Metabolic Gases
- H<sub>2</sub>O supply
- Food consumables
- Galley consumables
- Crew quarters
- Clothing
- Personal Equipment
- Personal Hygiene
- Health Maintenance
- Waste Collection
- Housekeeping
- Maintenance

Food consumables will consist of prepackaged, vacuum sealed, individual meals complimented with fresh foods. Vacuum sealed containers allow for a wide variety of prepackaged foods to be utilized in menu planning for extended periods, at a wide range of temperatures. Prepackaged meals must be supplemented with fresh foods to accommodate dietary requirements, as well as providing a palatable and balanced menu. Menu planning is of critical importance in extended duration missions for crew efficiency and psychological balance.

Galley consumables include cleaning supplies, maintenance consumables, and waste collection consumables.

Clothing will be washed in a clothes washer every seven days. Clothing consumables will be required for this.

### 5.4        Storm Shelter Operations

A solar storm shelter will provide significant solar and cosmic radiation protection for solar flare events.

The storm shelter is to allow reduced mode mission operations for a period of seven (7) days.

The shelter must provide significant protection to minimize radiation exposure to 5 Rem during a seven day period, at radiation levels of 400g/cm<sup>2</sup> corresponding to the flux levels of the 1972 solar event.<sup>5</sup>

## Section 5                      Mission Assumptions

### 5.4      Storm Shelter Operations

The shelter will provide facilities for:

- Closed system life support for the storm shelter environment during solar storm contingency operations.
- Earth and lunar surface communication systems.
- Computer interface providing support for systems monitoring, internal and external radiation monitoring, etc..
- Food consumables for a seven (7) day period, consisting of prepackaged, vacuum sealed individual meals. No food preparation facilities are to be required.
- Limited health maintenance facilities providing minor medical and emergency medical care.
- Limited waste management facilities providing for urination and defecation, body washing, oral hygiene and temporary wastes stowage.
- Sleeping facilities.

### 5.5      Extravehicular Activity

Extravehicular System Components required for mission operations are comprised of: <sup>6</sup>

- Crew lock
- EMU servicing, maintenance and recharge station
- EMU storage
- EVA tools and equipment
- EVA equipment caddie
- Equipment lock
- Modular EMU consumable augmentation kit for use on the rover, in support of extended EVA operations
- EVA system spare parts
- External and internal lunar dust control and removal equipment
- Deployable dust off shelter

Extravehicular activity is to follow a strategy of each two crew member team performing an EVA every third day.<sup>7</sup> Team A will EVA on the first schedule day , Team B on the second, and both teams will perform intravehicular activities on the third day. Additional EVA's will occur during transfer operations to the habitat module and the return transfer to the ascent vehicle.

## Section 5 Mission Assumptions

## Extravehicular Activity Schedule

<u>Day</u>	<u>Team A</u>	<u>Team B</u>	<u>Activity</u>
1	IVA	IVA	Crew lands on surface, transfer from flight to habitation mode
2	EVA	EVA	Contingency EVA, Operational Readiness Inspection of outpost
3	EVA	EVA	Rectify outpost discrepancies, transfer crew operations to habitat
4	IVA	IVA	Operational Readiness Inspection for manned mission mode
5	EVA	IVA	Certification of ORI and outpost operations
6	IVA	EVA	Certification of ORI and outpost operations
7	Rest	Rest	Personal activity
8	EVA	IVA	Deploy geophysical station and ISRU demonstration equipment
9	IVA	IVA	Life sciences, curation of geology samples, science conference
10	IVA	EVA	Geoscience traverse to astronomy/ physics zone
11	EVA	IVA	Geoscience traverse to astronomy/ physics zone
12	IVA	IVA	Life sciences, curation of geology samples, science conference
13	EVA	IVA	Near field exploration of lunar surface
14	Rest	Rest	Personal activity
15	IVA	IVA	Conduct lunar nighttime data transfer operations
16	EVA	IVA	Configure rover for instrument deployment, EVA maintenance
17	IVA	EVA	Configure rover for instrument deployment, EVA maintenance
18	IVA	IVA	Life sciences, curation of geology samples, science conference
19	EVA	IVA	EVA to emplace astronomy and physics instrumentation
20	IVA	EVA	Near field exploration of lunar surface
21	Rest	Rest	Personal Activity
22	EVA	IVA	EVA to emplace astronomy and physics instrumentation
23	IVA	IVA	Life sciences, curation of geology samples, science conference
24	IVA	EVA	Emplacement of heat flow experiments
25	EVA	IVA	Perform geoscience traverse
26	IVA	IVA	Life sciences, curation of geology samples, science conference
27	IVA	EVA	Perform geoscience traverse
28	Rest	Rest	Personal Activity
29	EVA	IVA	Near field exploration of lunar surface, ISRU processing
30	IVA	IVA	Life sciences, curation of geology samples, science conference
31	IVA	EVA	Perform geoscience traverse
32	EVA	IVA	Perform geoscience traverse
33	IVA	IVA	Life sciences, curation of geology samples, science conference
34	IVA	EVA	Conduct lunar noon data transfer operations
35	Rest	Rest	Personal Activity
36	EVA	IVA	Perform geoscience traverse
37	IVA	IVA	Perform IVA science activities
38	IVA	EVA	EVA activities in preparation for departure
39	EVA	EVA	Operational Readiness Inspection for unmanned mission mode
40	IVA	IVA	IVA transition from Manned Mission Mode to Habitat Mode
41	Rest	Rest	Rest before return trip to Earth
42	EVA	EVA	Transfer of crew operations from habitat to lander, departure
43	IVA	IVA	Allocated for contingency operations, Earth return
44	IVA	IVA	Allocated for contingency operations, Earth return
45	IVA	IVA	Allocated for contingency operations, Earth return

## Section 5                      Mission Assumptions

### Extravehicular Activity

A total of 28 two crew member team EVA's will be performed during mission operations.

#### 5.6      Space Suit Configuration

Extravehicular operations for the reference mission will utilize a high pressure, rigid suit design. The operational suit pressure will be in a range of 55.2 kN/m<sup>2</sup> to 57.2 kN/m<sup>2</sup> (8 psia to 8.3 psia).<sup>8</sup>

A high pressure, rigid suit design can be developed in the time frame of current lunar mission planning, and offers advantages in mission and program operations. Rigid suit development will be critical in achieving a sustainable and long term lunar development program, and should be accommodated in the initial stages of lunar planning. Current lunar studies must address issues of expandability and resource reutilization in the development of a permanent human presence in the lunar environment.

#### Advantages

- Reduction of Pre-breath times

Utilization of a high pressure suit design at 8 psia to 8.3 psia, in combination with a habitat design pressure of 10 psia will allow a reduction or elimination of oxygen pre-breathing prior to EVA operations. A high pressure suit design may allow the utilization of oxygen/ nitrogen mixtures during EVA.

- Stable Habitat Environment Pressurization

The reduction of pre-breathing operations, in conjunction with oxygen/ nitrogen mixture utilization will reduce pressurization complexities for mission operations and allow a stable pressurization environment in the habitat module. A stable pressurization environment is critical for scientific experimentation.

- Suit Lifetime

A high pressure, rigid suit design will allow an increase in suit durability and extended suit lifetimes. The extended suit lifetimes will provide for program longevity and a reduction of program costs for future lunar development. A rigid suit design will be critical in the extreme lunar environment. Cycle testing of metal space suit components revealed a 20 year lifetime for properly maintained bearings, and an indefinite lifetime for other suit components. Current shuttle suit design specifications provide for a cycle life of eight years, with full inspection after every five EVA's.

## Section 5                      Mission Assumptions

- Maintenance and Cleaning

Rigid suit components afford a reduction in suit maintenance, with the exception of flexible joints and bearings. Suit maintenance in the lunar environment may prove to be of significant cost reduction to the lunar program. The current protocol for suit maintenance for space shuttle operations entails 1500 hours of seam inspection, pressure leak checks, and PLSS refurbishment.<sup>9</sup> Metal suit components offer advantages in cleaning, from body functions as well as regolith abrasion.

- Crew member protection

A high pressure, rigid suit design will provide protection from micrometeorite strikes, as well as a degree of protection from solar and cosmic radiation during extravehicular activity. EVA operations in the lunar environment will be extremely hazardous, and current fabric suits designs are susceptible to rips and regolith abrasion, which could be critical to crew member safety.

### 5.7      Airlock Configuration

The airlock configuration is dependent upon mission requirements in the following areas.<sup>10</sup>

- Hyperbaric capabilities and associated needs
- Number of crew members utilizing the airlock at one time
- Size of LRU (Lunar Replaceable Unit) to be passed through the airlock
- Hatch and interior dimensions necessary to allow crew members and equipment to pass through the airlock
- Configuration and placement of equipment and materials storage racks

Hyperbaric operations must address the following requirements:<sup>11</sup>

- Recommended hyperbaric pressure is 2.8 Atm.
- The patient should remain horizontal and access to all sides of control equipment by the mission medical officer is required
- Medical equipment must be included to monitor, diagnose, and correct the patient's condition

## Section 5                      Mission Assumptions

### 5.8        Habitat Module

The habitat module is to support all crew operations for the mission duration, including extravehicular support and operations.

Habitat module development is based on a modified Space Station Freedom half module, 15'-0" in diameter, to conform to prior launch specifications. A 42" rack spacing has been determined to be optimal to accommodate most programmatic activities, and provide a standard for hardware modularity and reconfiguration. In instances where activities require more or less than one full rack, 1/2 rack subdivision will be used.

Module volume is determined from programmatic and volumetric analysis of mission requirements. It is considered that mission research objectives to determine minimum requirements to support initial lunar habitation, and provide for later lunar development stages critical in the development of realistic and obtainable solutions to First Lunar Outpost initiatives. It is additionally necessary to develop a satisfactory level of habitability to ensure high mission performance levels, due to high mission costs. These objectives may be met by the following strategies:

- (1).        To minimize programmatic and volumetric requirements of each activity.
- (2).        Allow for the combination of activities and adaptive utilization of space whenever feasible.
- (3).        Allow for a reconfiguration of facilities to accommodate a range of activities, and allow an adaptability of the habitat environment.

Modularity of the habitat environment is critical in achieving nominal mission operations, as well as future outpost operations. The extended time frame of both the First Lunar Outpost program, and mission duration must allow for a flexibility of program objectives, mission requirements and developing technologies. Future outpost operations will require a flexible environment to support mission objectives and programs as they are developed. A degree of modularity within the habitat environment will allow hardware and environment reconfiguration as required. A flexible environment will be required to respond to a variance in nominal mission operations, hardware failures, and contingency operations.

## Section 5                      Mission Assumptions

### 5.9      Subsystem Design

#### Rack and internal support systems

Habitat rack systems will be comprised of component subsystems in a modular environment. Subsystems will include support components at a 42" horizontal spacing, vertical separators, surface panels, and component utility buses. Component systems will allow a flexibility of operations and hardware reconfiguration, ease of maintenance, and subsystem redundancy.

#### Science hardware

Scientific hardware should be developed with a degree of modularity and flexibility due to mission variances and uncertainties. Whenever possible, adaptive utilization in component development should be considered.

## **Section 6                      Functional Requirements**

### **Functional Analysis**

Operations/ Communications  
Galley  
Dining  
Crew Quarters  
Personal Hygiene  
Health Maintenance  
Exercise Facilities  
Stowage  
EVA functions  
Science/ Laboratory

### **Functional Requirements**

#### **Crew Quarters**

- Sleeping Facilities
- Personal Grooming/ Dressing
- Personal Storage
- Personal Workstation
  - Computer/ Television
  - Audio Equipment
  - Communications

#### **Storm Shelter**

- Communications
- Consumables Access and Management
- Trash Management
- Waste Management System
- Personal Hygiene
- Health Maintenance/ Monitoring

#### **Galley**

- Ovens
- Refrigerator
- Freezer
- Dry Food/ Beverage Storage
- Ambient Storage
- Utensils Storage
- Water Dispenser
- Handwash
- Trash Compactor
- Food Preparation Area
- Clean Up Facilities



## Section 6                      Functional Requirements

### Health Maintenance

- Sterilization Preparation Area
- Blood Analysis
- Electrocardiograph
- X-Ray Equipment
- Health Monitoring Systems
- Minor Surgery Capabilities
- Oxygen Regulator
- Oxygen Storage
- Anesthesia Facilities
- HMF Stowage

### Exercise Facilities

- Rowing Machine
- Stationary Bicycle
- Health Monitoring Systems

### Personal Hygiene

- Shower
- Hand/ Face Cleansing
- Oral Hygiene
- Personal Hygiene Stowage
- Toilet Facilities
- Waste Stowage
- Waste Reclamation
- Laundry Facilities

### Operations/ Communications

- Communications Functions
  - Lunar Base to Earth Communications
  - Lunar Base to Ci-lunar Orbit Communications
  - Lunar Base to Separated Lunar Functions
  - Lunar Module to EVA Base Activities
- Computational Functions
- Monitoring Systems
  - Module Environment
    - Module Equipment
    - ECLSS Monitoring
    - Data Collection and Analysis
    - Research Equipment
  - Surface Environment
    - EVA Monitoring Systems
    - Telerobotics Systems
    - Research Control Systems
    - Base Environmental/ Power Systems
- Information Management Systems

## **Section 6                      Functional Requirements**

### **Wardroom**

- General Dining
- Meeting Facilities
- Recreation/ Leisure
- Access to Communications/ Information Management Systems

### **Stowage**

- Oxygen/ Hydrogen/ Nitrogen Storage
- Supplies Storage
  - Food Supplies
  - Medical Supplies
  - Hygiene Supplies
  - Clothing
- Wastes Storage
- Trash Storage
- Equipment Maintenance/ Replacement
- Science Equipment Storage

### **Science/ Laboratory**

- Photography
- Astronomical Sciences
- Geological Sciences
- Chemical Analysis
- ISRU Processing

### **EVA functions**

- Airlock Facilities
- EVA Suit Storage
- EVA Equipment Storage
- Monitoring Systems
- Communications Systems

## Consumables Analysis

## Consumables Requirements - Open Loop System

Consumable	Utilization	Indiv./ Day (lbs.)	Crew/ Day (lbs.)	Mission	Volume
		(kg.)	(kg.)	(lbs.)	(Cu. ft.)
Metabolic Gases	Oxygen (27%)	1.82	7.31	329.37	3692.10
	Nitrogen (73%)	4.92	19.68	885.60	14768.4
Water (Habitat)	Potable drinking	4.10	16.40	738.00	11.83
	Food water	1.10	4.40	198.40	3.18
	Food preparation	1.10	4.40	198.40	3.18
	Hand wash	3.97	15.87	714.89	11.45
	Hygiene	0.79	3.17	142.86	2.29
	Shower/ hygiene	7.90	31.74	1428.59	22.90
	Toilet flush	1.10	4.40	198.41	3.18
	Clothing wash	28.10	112.35	5055.00	81.03
	EHS sample	0.41	1.69	76.50	1.23
	Total Water	48.60	194.46	8756.00	140.37
Food Consumables	Ambient Storage	1.54	6.17	277.00	45.36
	Frozen Storage	0.21	0.88	39.00	5.67
	Foods Packaging	0.46	1.76	19.36	5.67
	Total Foods	2.20	8.80	396.80	56.70

## Section 7

## Consumables Analysis

## Consumables Requirements - Partially Closed Loop System

Consumable	Utilization	Percent Recapture	Indiv./ Day (lbs.)	(kg.)	Crew/ Day (lbs.)	(kg.)	Mission (lbs.)	(kg.)	Volume (Cu. ft.)
Metabolic Gases	Oxygen (27%)	90 %	0.18	0.08	0.72	0.32	32.40	14.40	923.01
	Nitrogen (73%)	90 %	0.49	0.22	1.96	0.88	88.20	39.60	3692.1
Leakage Gases	Oxygen	0 %	N/A	N/A	1.10	0.50	49.60	22.50	556.00
	Nitrogen	0 %	N/A	N/A	3.90	1.77	175.60	79.65	1968.00
	Gases Total		N/A	N/A	7.68	3.47	345.80	156.15	7139.11
Water (Habitat)	Potable drinking	0 %	4.10	1.86	16.40	7.44	738.00	334.8	11.83
	Food water	0 %	1.10	0.50	4.40	2.00	198.40	90.00	3.18
	Food preparation	90 %	0.11	0.05	0.44	0.20	19.84	9.00	0.31
	Handwash	90 %	0.40	0.18	1.59	0.72	71.49	32.40	1.15
	Hygiene	90 %	0.08	0.04	0.32	0.14	14.29	6.24	0.23
	Shower/ hygiene	90 %	0.79	0.36	3.17	1.44	142.85	64.80	2.29
	Toilet flush	90 %	0.11	0.05	0.44	0.20	19.84	9.00	0.32
	Clothing wash	90 %	2.81	1.27	11.24	5.10	505.50	229.30	8.10
	EHS sample	0 %	0.41	0.19	1.69	0.77	76.50	34.70	1.23
	Sub Total Water		9.91	4.50	39.69	18.01	1786.71	810.24	28.64
H2O Recovery	Respiration	90 %	3.61	1.64	14.44	6.56	649.80	295.20	10.43
	Urine H2O	90 %	2.97	1.35	11.88	5.40	534.60	243.00	8.58
	Total Water		3.33	1.51	13.37	6.05	602.31	272.04	9.63

## Section 7

## Consumables Analysis

## Consumables Requirements - Nominal Mission

Requirement	Utilization	Mission (lbs.)	(kg.)	Volume (Cu. ft.)
Consumables	Galley	193.25	87.66	13.66
	Clothing	151.00	68.80	20.49
	Crew quarters	143.00	65.30	27.92
	Personal equipment	439.00	63.40	4.95
	Personal hygiene	98.50	44.50	5.65
	HMF consumables	-----	-----	-----
	Waste collection	117.90	53.50	15.56
	Housekeeping	149.90	68.00	6.36
	Maintenance	9.90	4.50	0.71
	Totals			

## Equipment Requirements - Nominal Mission

Requirement	Utilization	Mission (lbs.)	(kg.)	Volume (Cu. ft.)
Equipment	Operations/ Communications	-----	-----	-----
	Galley supply	657.63	298.30	83.09
	Crew quarters	125.80	57.10	
	Personal equipment	91.27	41.40	
	Personal hygiene	396.60	179.90	
	HMF equipment	-----	-----	-----
	ECLSS	-----	-----	-----
	Waste collection	257.00	116.90	25.81
	Housekeeping	310.85	141.00	11.31
	Maintenance	278.00	126.00	14.84
	Totals			

## Section 7

## Consumables Analysis

## Consumables Requirements - EVA Activity

Consumable	Utilization	Indiv./ EVA (lbs.)	(kg.)	Crew/ EVA (lbs.)	(kg.)	Mission (lbs.)	(kg.)	Volume (Cu. ft.)
Metabolic Gases	Oxygen(27%)	0.33	0.16	0.66	0.32	18.48	8.96	45.36
	Nitrogen(73%)	0.90	0.44	1.80	0.88	50.40	24.64	122.64
Gas Losses	Airlock	N/A	N/A	1.22	0.60	34.16	16.80	85.00
EVA water	Potable drinking	9.67	4.39	19.35	8.78	541.90	245.84	8.69
	Waste water	2.00	0.91	4.00	1.82	112.34	50.96	1.80

## Section 8 Habitat Configuration A

### 8.1 Crew Quarters

#### Design Strategies

Lunar gravity will require crew members to sleep in a horizontal position. The crew members will require headroom for sitting, knee room and space for turning during sleep.

Crew quarters are to emphasize the importance of privacy, and to provide personal storage and recreation facilities.

Crew quarter configuration must address reconfiguration modes, ingress and egress, circulation pathways, dust management and cleaning.

#### Configuration

Several crew quarters concepts were evaluated for volumetric requirements, spatial reconfiguration, and solar and cosmic radiation protection. The proposed below deck configuration allows an optimization of rack utilization, and provides a maximum level of crew privacy, while providing for personal activity. The proposed design allows a combination of the activities of crew quarters, personal recreation and storm shelter.

The crew quarters concept clusters individual sleeping and personal recreation areas around a common access hatch and vestibule. The hatch remains open during nominal mission operations, allowing access and egress as required. Sliding partitions between crew quarters provide circulation and access during contingency operations, as well as allowing an open contiguous space. Each crew quarter is provided with a variable geometry recliner, portable workstation, personal storage space and storm shelter consumables. The variable geometry recliner provides for sitting and sleep configurations, and addresses an anthropomorphic design range. The portable workstation system will be interfaced to operations and communications, providing personal communications, video, audio, computing and recreational functions, as well as access to critical mission functions. Modular and task lighting is provided to accommodate a range of activities.

## Section 8                      Habitat Configuration A

### 8.2      Storm Shelter

The crew quarters are to serve as the storm shelter envelope during solar storm contingency operations. Solar and cosmic radiation protection is provided through the implementation of a water bladder surrounding the crew quarters facilities, containing both fresh and waste water requirements for the mission. Fresh and waste water are separated in segmented compartments within the water bladder.

The calculated mission H<sub>2</sub>O requirements are based on an open loop system, and does not address H<sub>2</sub>O recirculation and reuse. The calculated H<sub>2</sub>O volume is approximately 140 ft.<sup>3</sup>. This H<sub>2</sub>O volume will provide 10.4 cm bladder for the crew quarter volume. A partially closed loop system would reduce mission H<sub>2</sub>O requirements.

A shielding level of 20 g/cm<sup>2</sup> may be obtained through the utilization of a 10.4 cm H<sub>2</sub>O bladder in conjunction with a 1.7 cm aluminum casing. The shielding requirements do not address additional shielding provided through the module structure and equipment. The lander and fuel tanks will provide an additional amount of shielding from deflected cosmic particles.

The storm shelter is to allow reduced mode mission operations for a period of seven (7) days. During solar storm contingency operations, the crew quarter hatch will be secured, and a closed system environmental control and life support system will be operational within the shelter environment, providing contamination protection from the habitat environment. The storm shelter is to be a self contained environment, therefore critical life support functions are to be contained within the shelter envelope. Storm shelter consumables for a seven (7) day period are provided in designated crew quarter storage racks. The crew quarter racks are deployable, allowing servicing of equipment located behind the racks. The shelter will provide food consumables consisting of prepackaged, vacuum sealed meals. No food preparation facilities are provided. Limited waste management facilities are provided for urination and defecation, body cleansing, oral hygiene and temporary wastes storage. Limited health maintenance facilities are provided for minor medical and emergency medical care, consisting of a health maintenance glove box.

Mission operations during solar storm contingency operations will be in reduced mode. Each crew quarter is provided with a portable workstation, interfaced with the operations and communications workstation, allowing communications control from each workstation. The portable system will support critical mission functions, as well as individual communications, computational and recreational activities. The system will be interfaced to external sensors to provide monitoring of external radiation levels, as well as support of solar storm experiments.



## Section 8                      Habitat Configuration A

### 8.3      Galley

Food storage for a seven (7) day resupply cycle will be provided in the galley area. Food storage will include ambient and refrigerated foods. Food consumables will be resupplied from the logistics module, with environmentally controlled access from the habitat module. The galley storage racks are configured with modular storage drawer that are to be exchanged with storage drawers in the logistics module. The modular storage drawers are utilized in food consumables resupply and galley waste management.

The mission menu will consist of prepackaged, vacuum sealed, individual meals complimented with fresh foods. Prepackaged meals must be supplemented with fresh foods to accommodate dietary requirements, as well as providing a palatable and balanced menu.

The galley configuration addresses mission planning and menu configuration strategies. A major component of the mission menu consists of prepackaged meals that are to be heated in the dual microwave ovens. Vacuum sealed containers may be accommodated at a wide temperature range, and are to be stored in ambient food storage racks in the galley area. Prepackaged meals are supplemented with fresh foods to be consumed uncooked. A freezer and refrigerator are provided to accommodate fresh food consumables. A trash compactor is provided for the disposal of food packaging, and compacted waste is stored in the logistics module. Utensil storage is provided for trays, plates, drinking containers, and eating utensils. Utensils will be cleaned in the dishwasher after meals. A rehydration port is provided for dehydrated consumables, as well as an H2O dispenser.

## **Section 8                      Habitat Configuration A**

### **8.4        Health Maintenance**

#### **Design Strategies**

Health maintenance facilities must provide for minor medical procedures, as well as emergency medical care. Nominal operations of the health maintenance facility are to be diagnostic and monitoring procedures, and health care. Diagnostic and monitoring procedures are to evaluate crew physiological and psychological status, and support life sciences research. Preventative health maintenance is to involve dental and physical examination, etc..

Exercise facilities will be required for extended mission operations and may be accommodated in the health maintenance facility. Exercise is required to counteract bone mineral loss, muscular strength loss, and cardiovascular decrease, as well as providing psychological and sociological balance in a confined environment. Exercise facilities must be storable and compact, and provide maximum physical benefit.

Exercise facilities may accommodate recreational activities, to provide an environment that encourages crew exercise on a regular schedule.

#### **Configuration**

The health maintenance and exercise facilities are combined in a 1 1/2 rack configuration. Physiological monitoring capabilities are provided through the HMF computer system, which will be utilized for routine life functions monitoring, surgical monitoring and exercise activities. All HMF equipment will interface to the HMF computer system, allowing surveillance of all HMF functions. The computer monitor will be a high resolution color graphics display, capable of color imaging techniques and graphical overlay. The HMF system will additionally support video display for the exercise facilities, driven from laser storage technologies.

A deployable examination and surgical table is provided for psychological monitoring and minor surgical procedures.

Exercise equipment consists of a deployable ergonometer and rowing machine, to accommodate upper and lower body exercise. The equipment is deployed from the front panel of the HMF facility, and is reconfigured as either ergonometer or rowing machine. A deployable treadmill is additionally provided for running and walking exercise.

HMF equipment and consumables storage is provided in a half rack adjacent to the HMF operations facility. Equipment critical to HMF operations include electrocardiograph, X-ray, oxygen regulation and storage, anesthesia, and blood analysis.

## Section 8                      Habitat Configuration A

### 8.5      Personal hygiene

Mission operations will require strict personal hygiene standards for biomedical and psychological reasons. Hygiene conditions within the module will significantly affect the compatibility of the crew members. The hygiene facility is to accommodate daily utilization, involving showering, hand and facial cleansing, oral hygiene, and toilet facilities.

Personal hygiene facilities provide an enclosed shower, toilet facilities, handwash, deployable sink for oral hygiene, and hygiene storage space for consumables and personal affairs. The configuration allocates 1 1/2 racks, and allows utilization of the hygiene facilities by two crew members simultaneously. The shower is equipped with an air blower to remove excess water from the crew members and shower walls, that is collected in a floor drain. Waste water is processed and reused for the shower and toilet facilities. Solid wastes from the toilet facilities are to be compacted and stored, and waste water is to be processed.

### 8.6      Operations/communications

The operations and communications facilities must support all mission objectives and provide computational and communications functions for all crew members.

To achieve an effective operational environment and a flexibility in application, while addressing effective space utilization, a strategy has been considered involving an integrated computer and communications network interfaced to primary and redundant secondary processing units. The hardware configuration considered optimal supports a dedicated operations and communications workstation, and a portable workstation system interfaced to data ports in critical locations in the habitat environment.

The dedicated workstation will be required for computationally intensive activities, and should provide a highly interactive environment capable of support of complex information management, high graphics output, and multiple and mixed mode configuration. The dedicated workstation will support communications, systems monitoring, EVA support, telerobotic and telepresence application.

The portable workstation will be a reduced mode system, able to support critical mission functions, and supporting individual communications, computational and recreational activities. The portable workstation system must provide a modular environment to support a flexibility of applications and operational modes.

Primary communications functions will be dedicated to the operations workstation, particularly critical operations involving data and program linking and status communications. The portable workstation system will provide linked communications facilities to the operations and communications workstation, allowing communications control from each workstation node.

The portable workstation system will be the primary communications interface during storm shelter contingency operations.

## **Section 8                      Habitat Configuration A**

### **8.7        Wardroom**

Wardroom and dining facilities are non permanent activities, therefore are accommodated with a deployable system. A wardroom table accommodating four (4) crew members is deployable from a ceiling mounted track system. The wardroom table is collapsed and stowed when not in use. The track system is provided for the length of the habitat module, allowing utilization of the table facility in variable configurations. The table may be utilized for additional workspace in any operational facility, as well as providing dining and meeting accommodations. Seating is accommodated through a collapsible seating system, which will be utilized for all seating functions, involving wardroom and dining, operations and communications, and science facilities. A deployable chair will be provided for each crew member.

### **8.8        Science/Laboratory**

The science facilities must provide for a variety of experimentation in the areas of materials processing, crystal growth, biological and life sciences experimentation and partial gravity experimentation. The science facility will allow a modularity of components to provide for program flexibility during mission operations. Component modularity should facilitate a reconfiguration or replacement of science hardware, with consideration for future mission operations.

The science facility configuration supports a science glove box and maintenance facility, and experimentation facility. The science glove box and maintenance facility is intended as a workbench for equipment repair and modification, and workspace for the science facilities. An adjustable counter space and equipment and spare parts storage drawers are provided. The experimentation facility is a modular rack system providing power requirements for experiment components.

The science and laboratory facility will support:

- Photography
- Astronomy
- Geology
- Chemical analysis
- In Situ Resource Utilization (ISRU) processing
- Materials storage

## Section 8                      Habitat Configuration A

### 8.9        Logistics

A pressurized, thermally controlled logistics module is supplied for consumable resupply. The logistics module will be transferred from the crew module utilizing an unpressurized rover, and attached to the habitat module during transfer operations. The logistics module will be lifted and attached using mechanical assistance. A candidate system for attachment operations is an electric winch and pulley system, providing a compact and light weight system with a minimum level of complexity.

The logistics module configuration contains an external pressure shell, interior storage drum, and access hatch. The logistics module hatch is to be coupled to the secondary access hatch of the habitat module, providing environmentally controlled access during mission operations. Environmental and thermal control equipment is located in the end cones of the logistics module. The interior storage drum of the logistics module rotates, allowing access to the entire volume. Consumables and waste storage areas are separated and compartmentalized within the storage drum. Resupply operations are accommodated through the utilization of modular storage drawers that are exchanged with rack drawers in the habitat module. Empty drawers are stored in the logistics module. Waste containers will be exchanged during resupply operations , and additionally stored in the logistics module.

The logistics module is ideally returned to an LEO node or to Earth with the crew return vehicle for resupply operations in future lunar outpost operations. The logistics module may be transferred to the ascent vehicle utilizing the rover during retransfer operations. If operational costs prove to be prohibitive, the logistics module may be detached and remain on the lunar surface. A reutilization of the module in future lunar outpost operations is desirable.

### 8.10        Airlock Configuration

The airlock configuration was determined to be independent of the habitat configuration, therefore was treated as an independent study. The assumptions determined for the airlock configuration support a design accommodating four (4) crew members at one time, due to contingency and emergency operational concerns. This airlock may support EMU storage, with rigid suits to be suspended for storage and suit donning, and provided with rear entry hatches for access and egress.

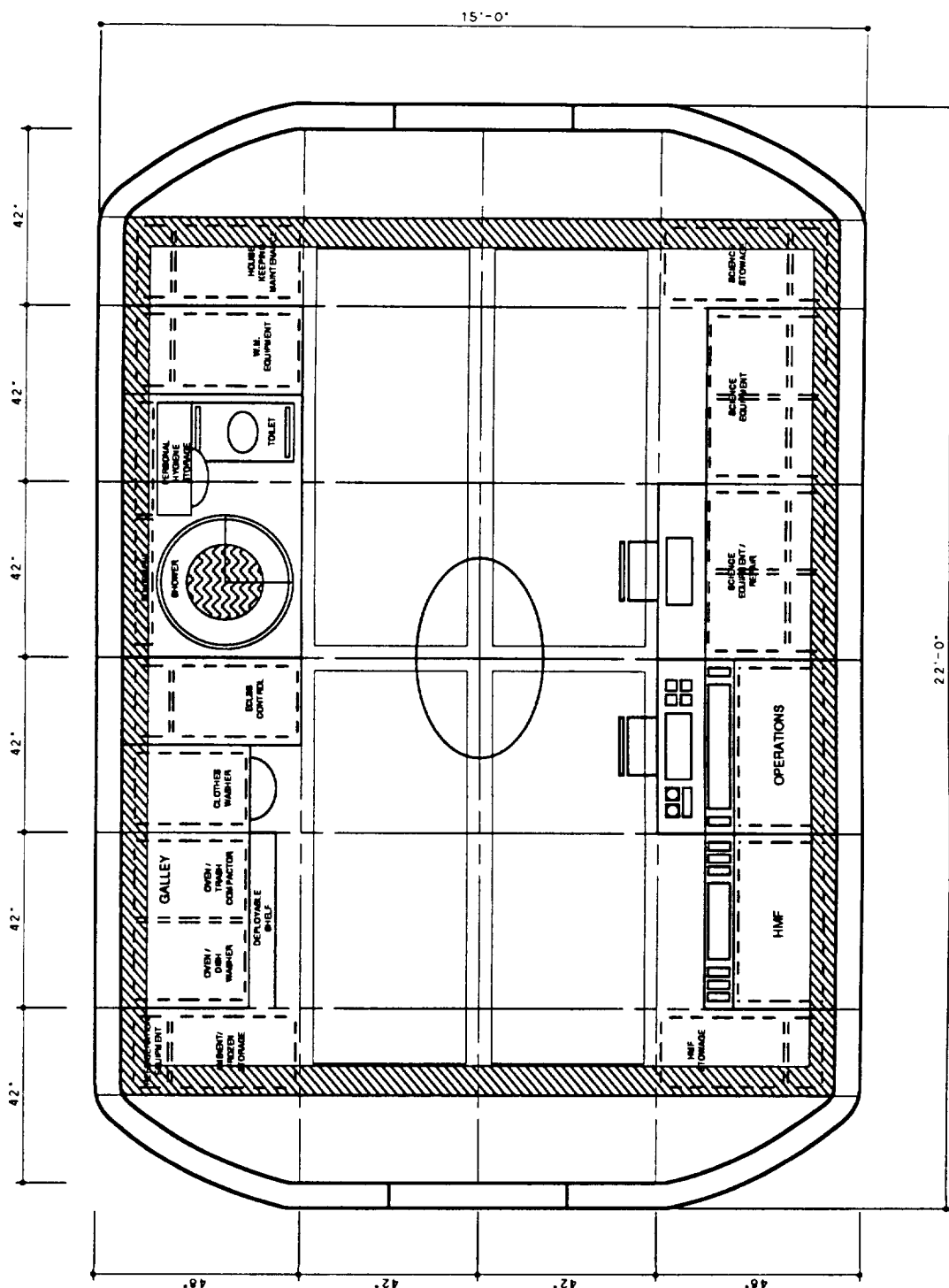
Hyperbaric treatment may be accommodated within the envelope of this airlock, with life sciences monitoring systems networked to the HMF computer systems. The hyperbaric treatment facility would be deployable, and stowed during nominal mission operations.

Equipment stowage may be accommodated externally to the airlock, and would offer considerable advantages if stowed at the surface level, rather than at the level of the habitat module. Accommodation must be made for materials stowage for scientific experimentation and geological examination, in providing a temporary stowage facility within the airlock, for utilization prior to materials transfer to the science and laboratory facilities within the habitat module.



## Section 8

### Habitat Configuration A

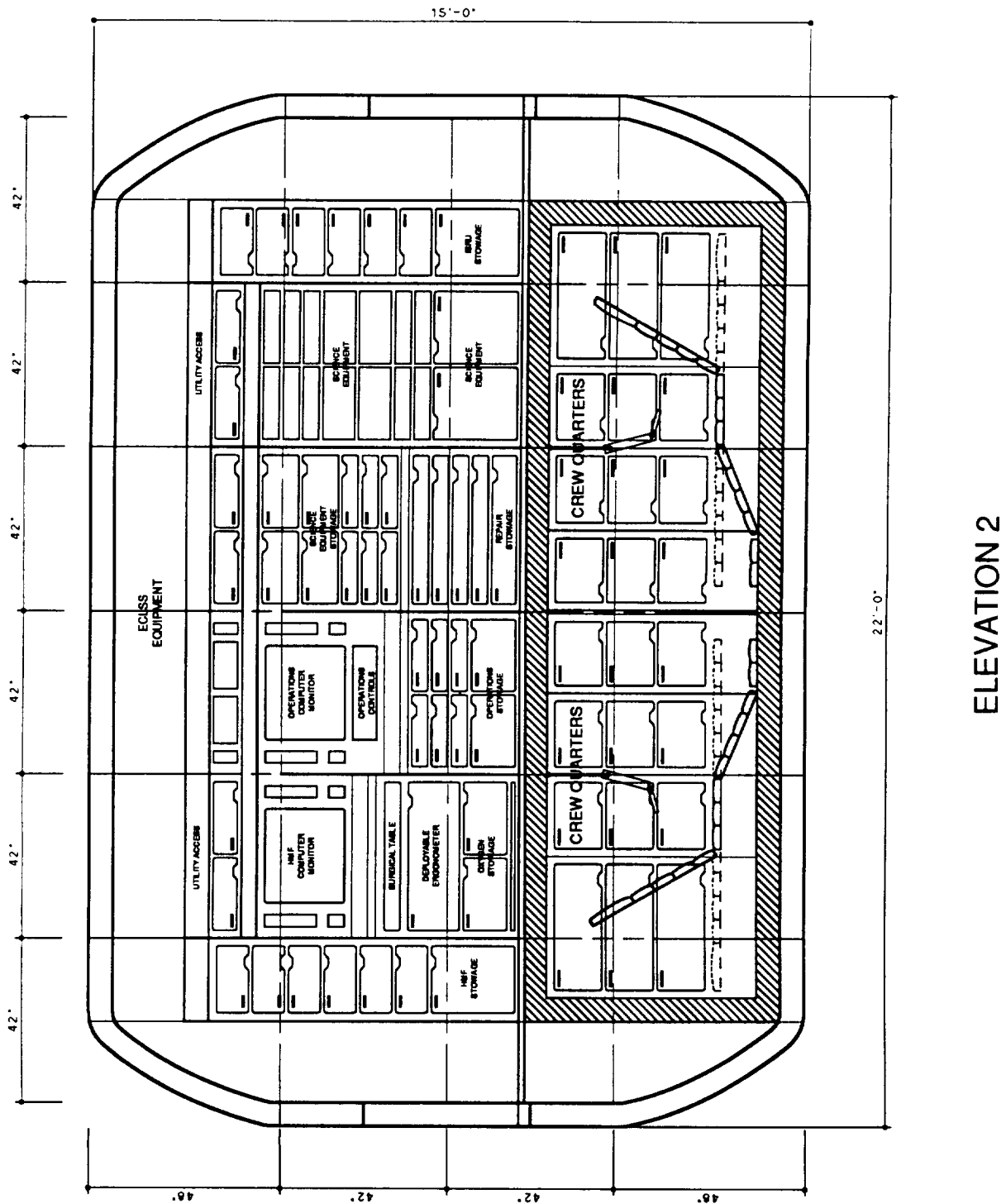






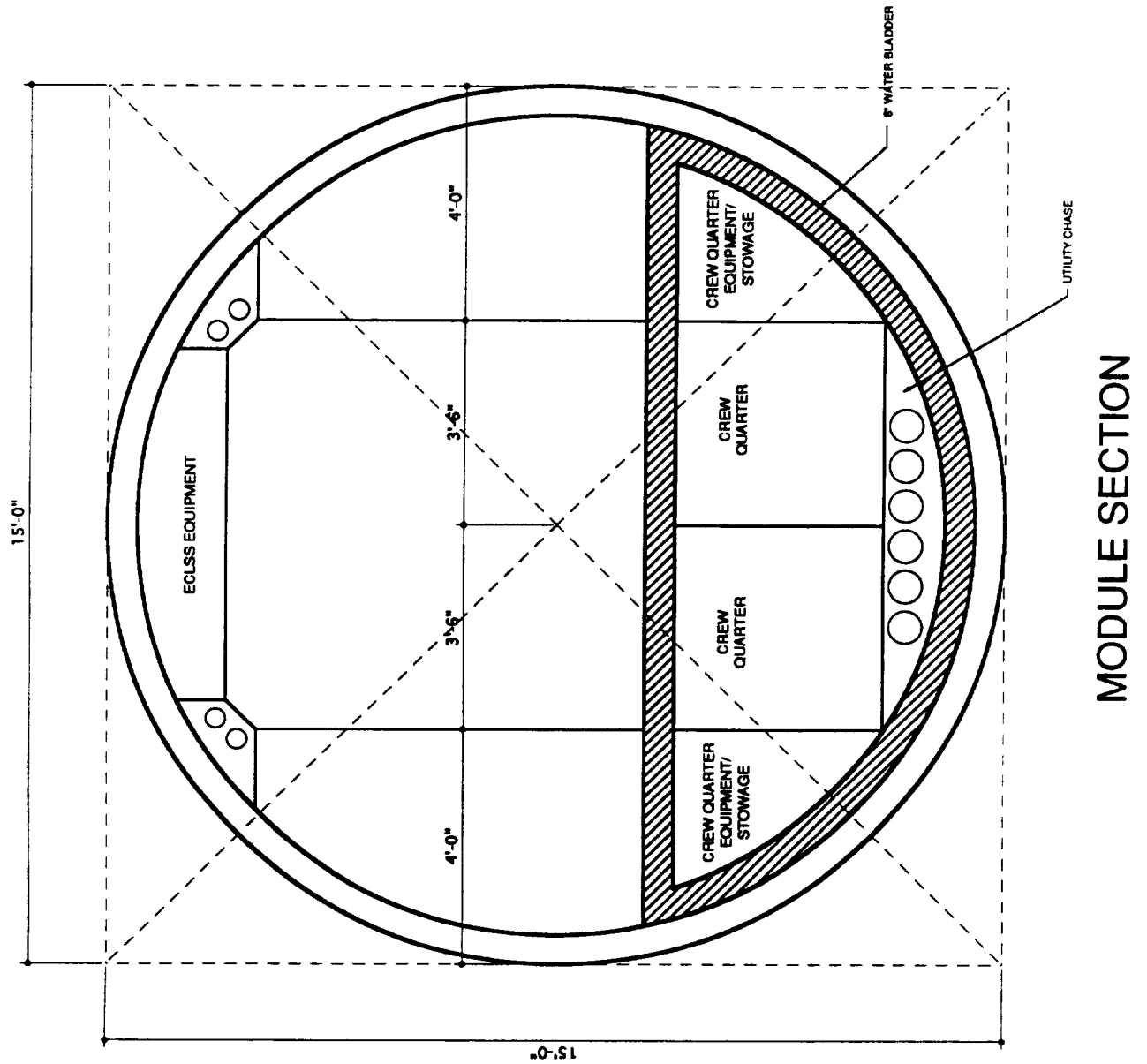
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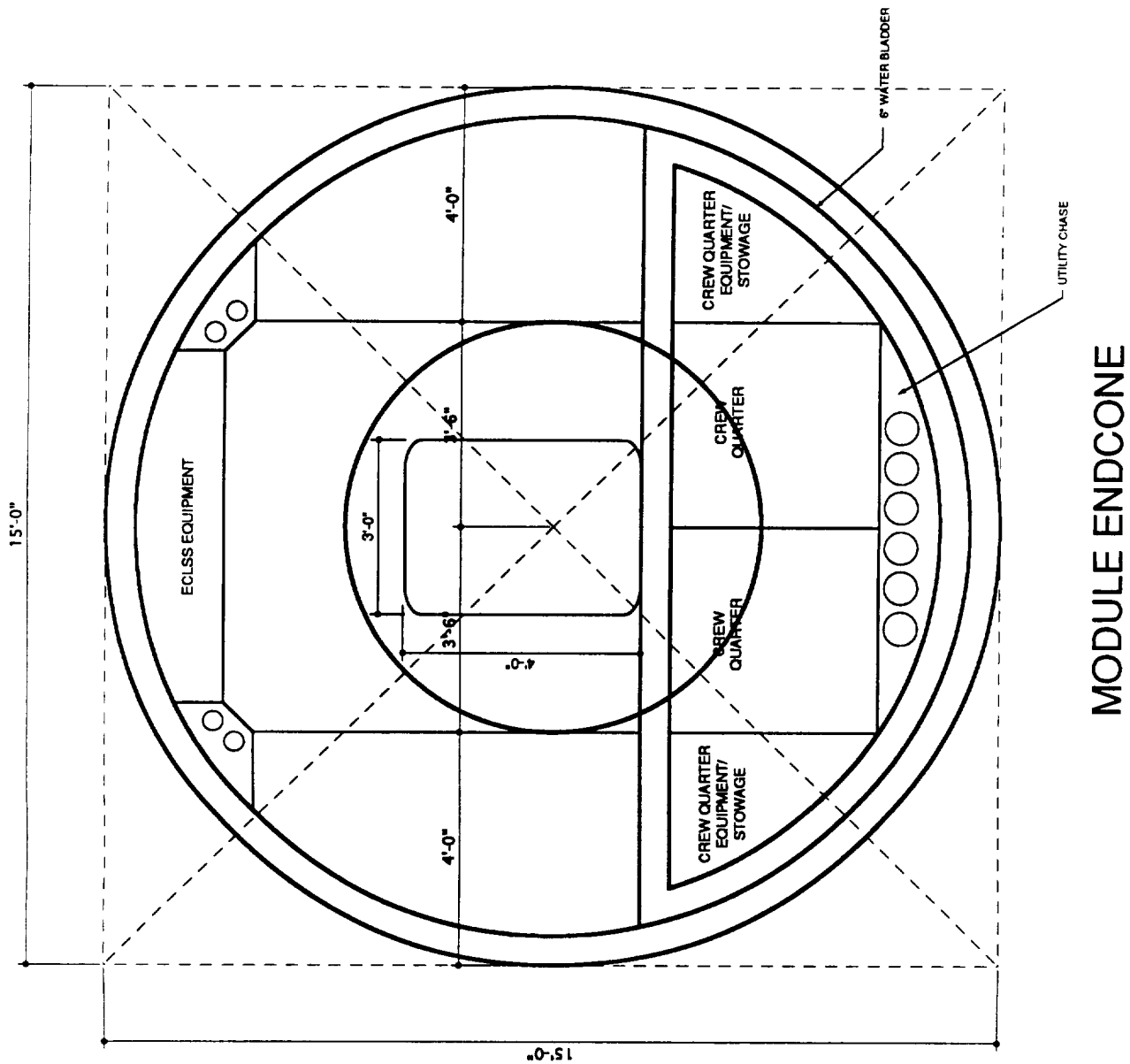
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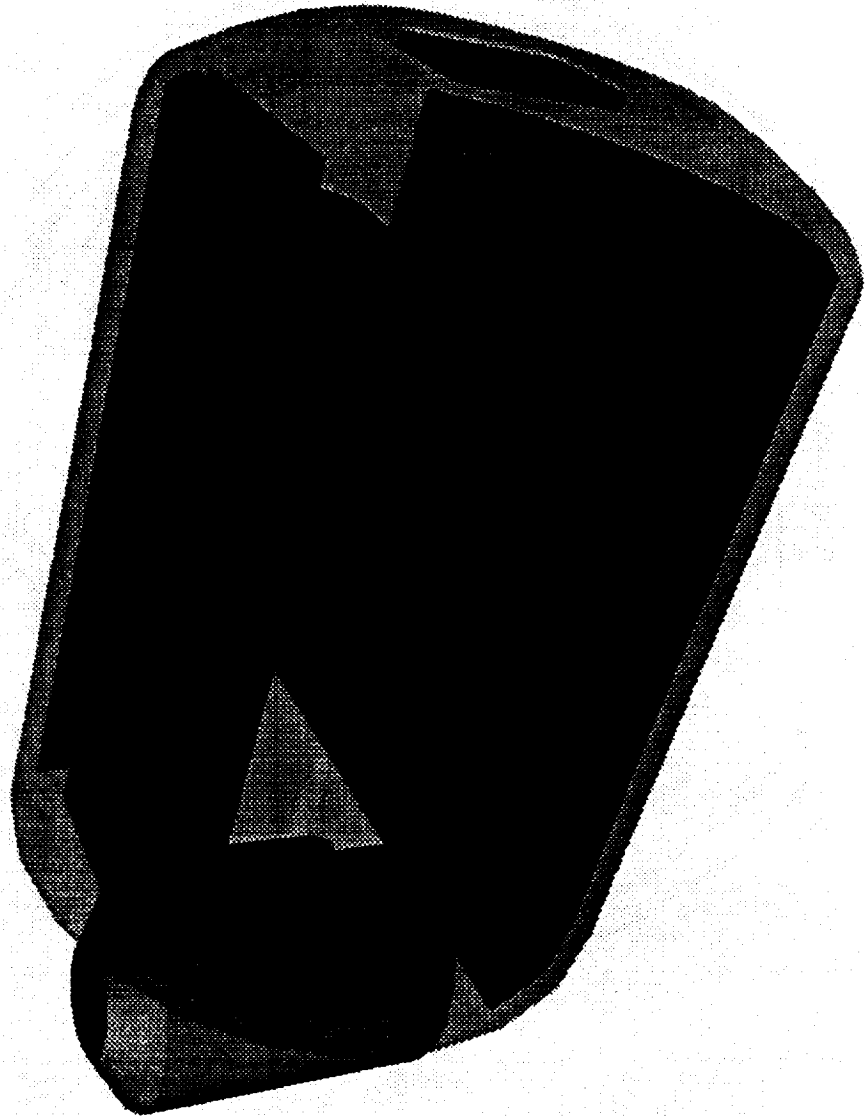
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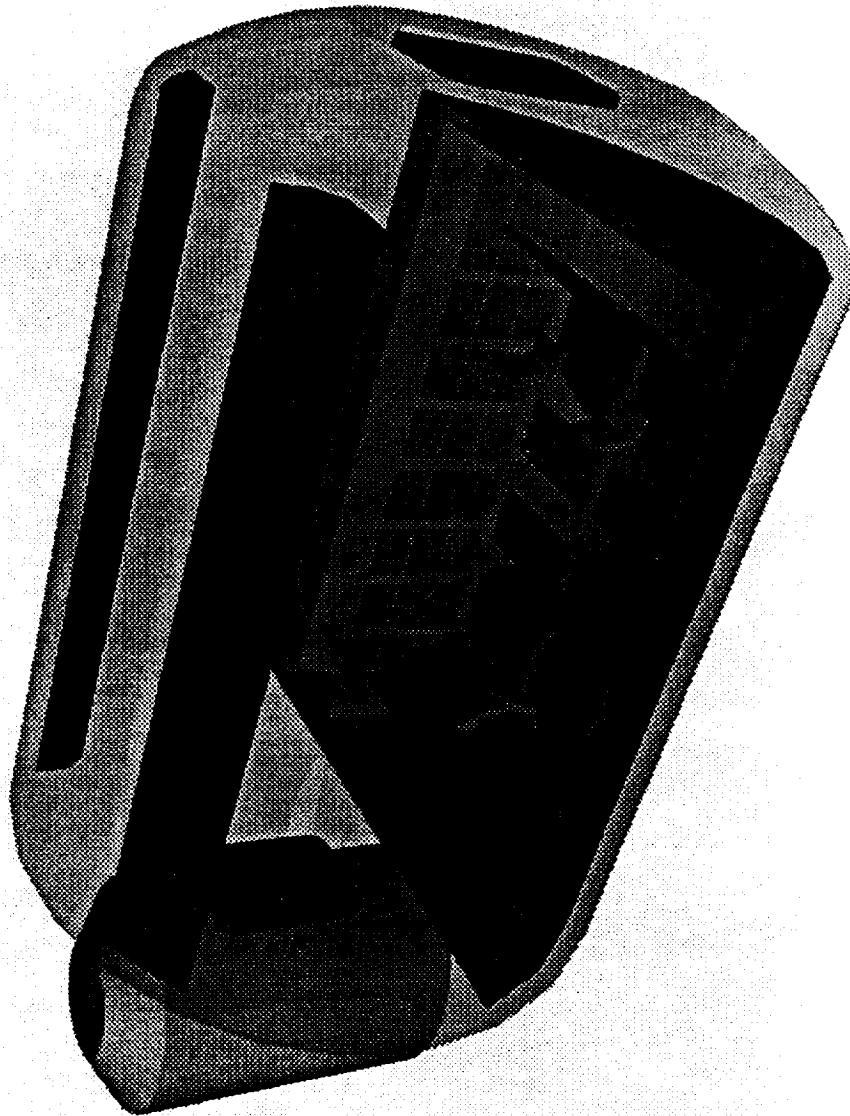
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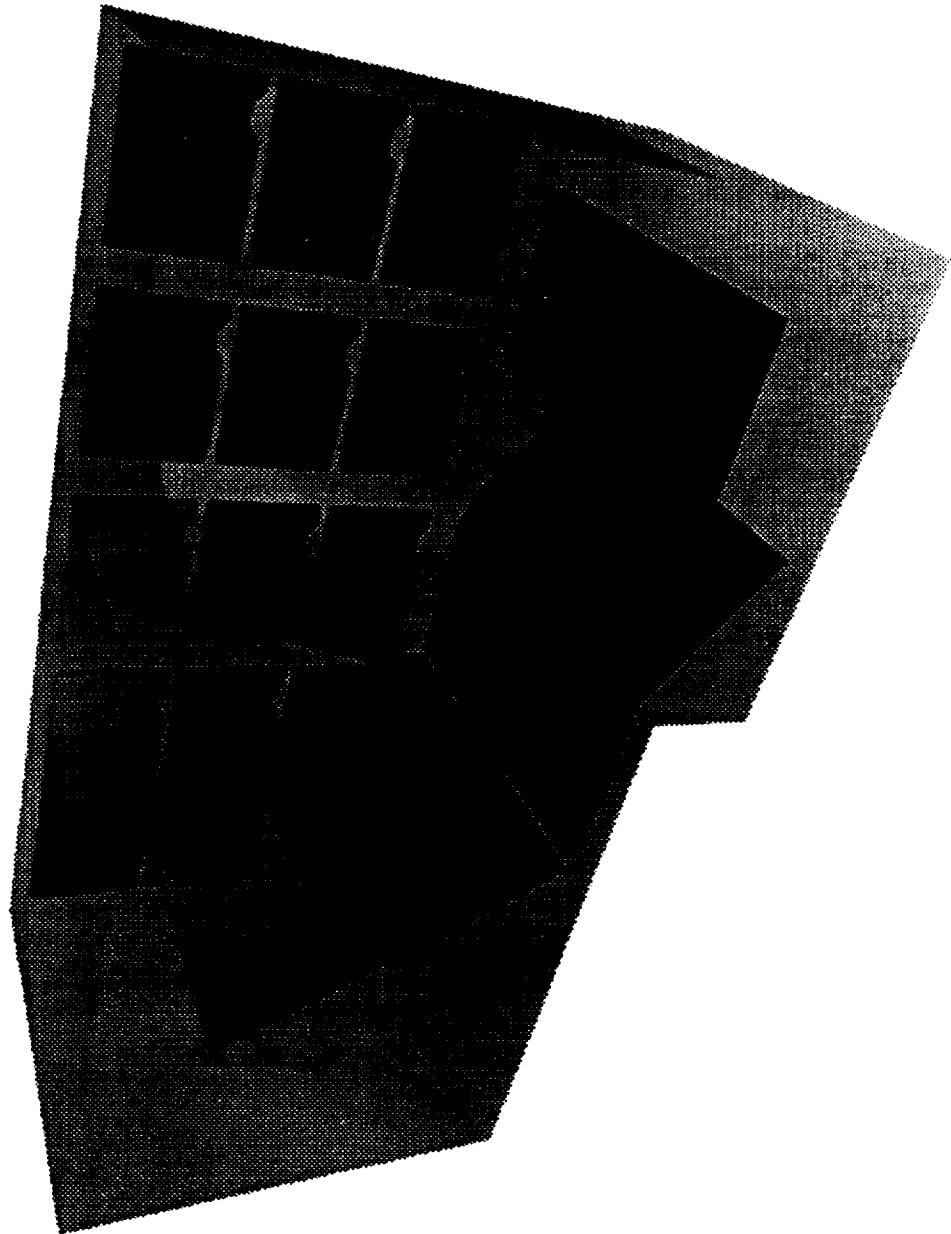
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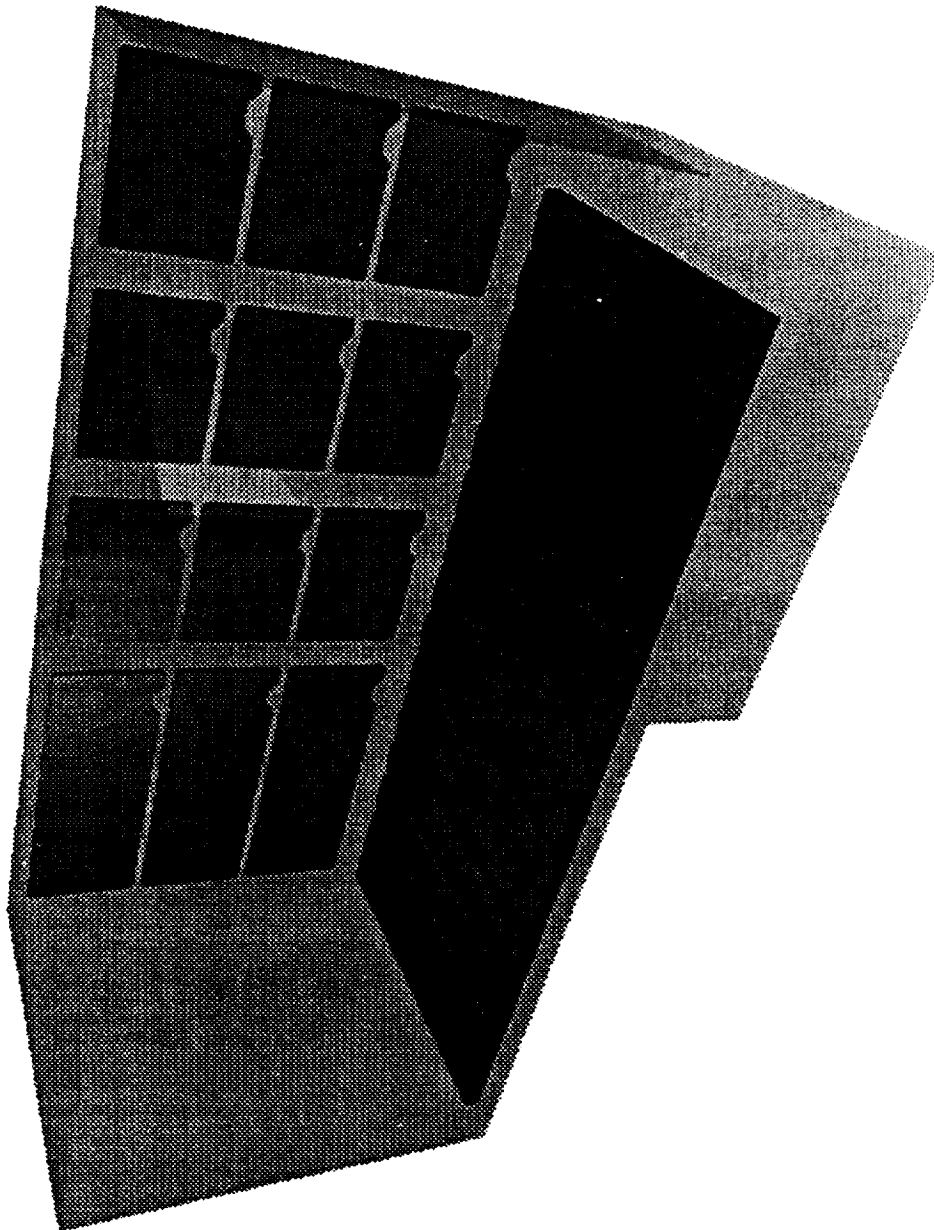
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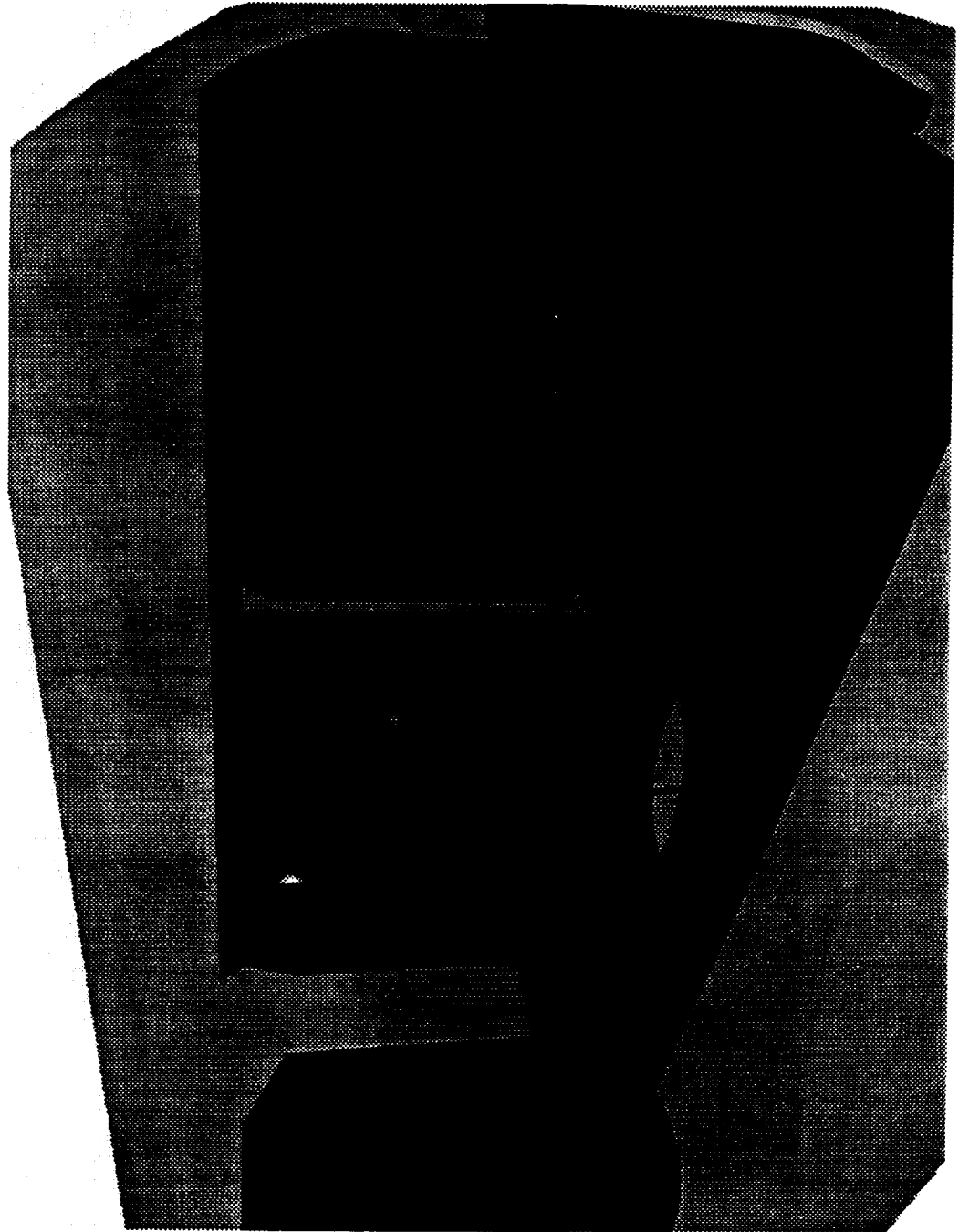
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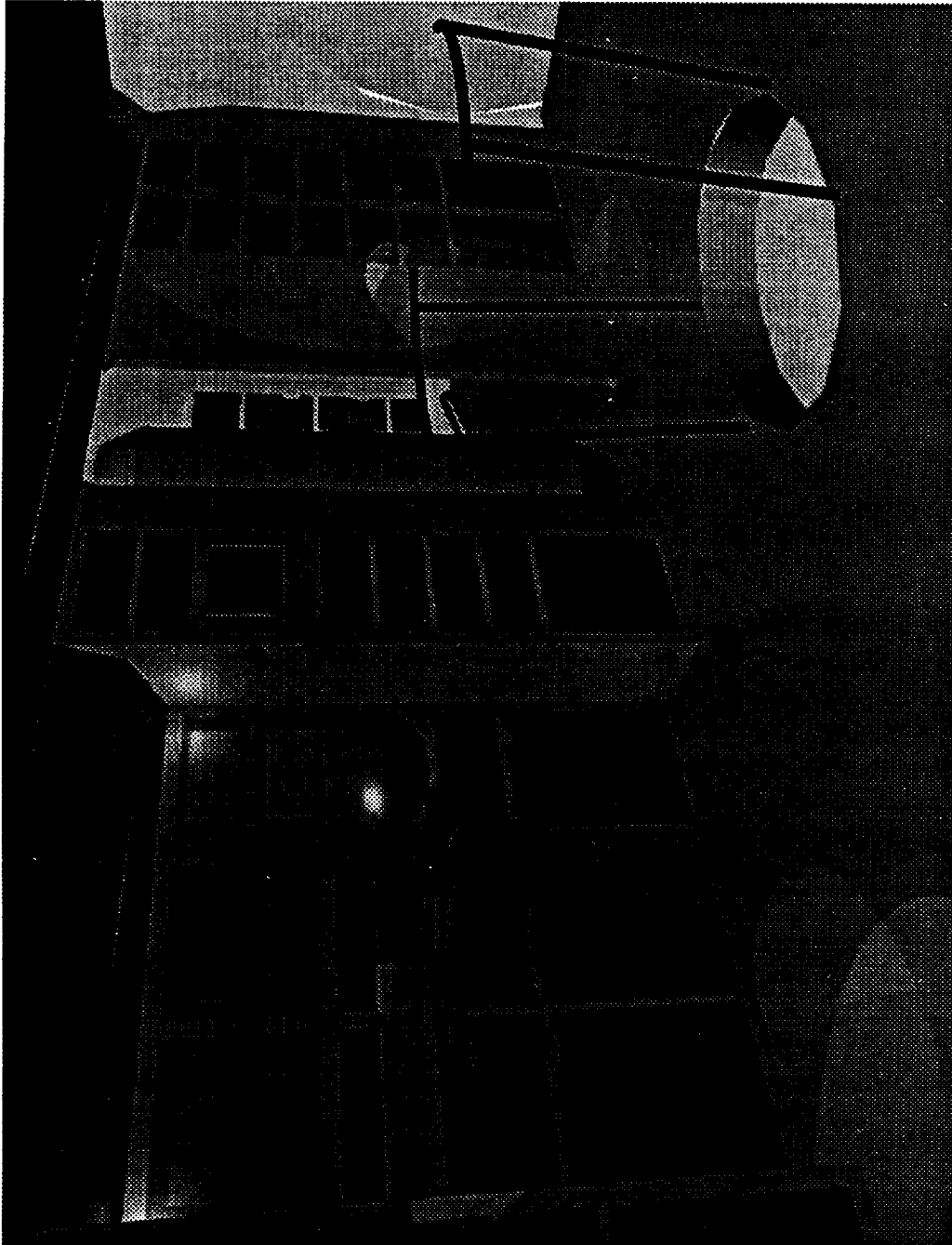
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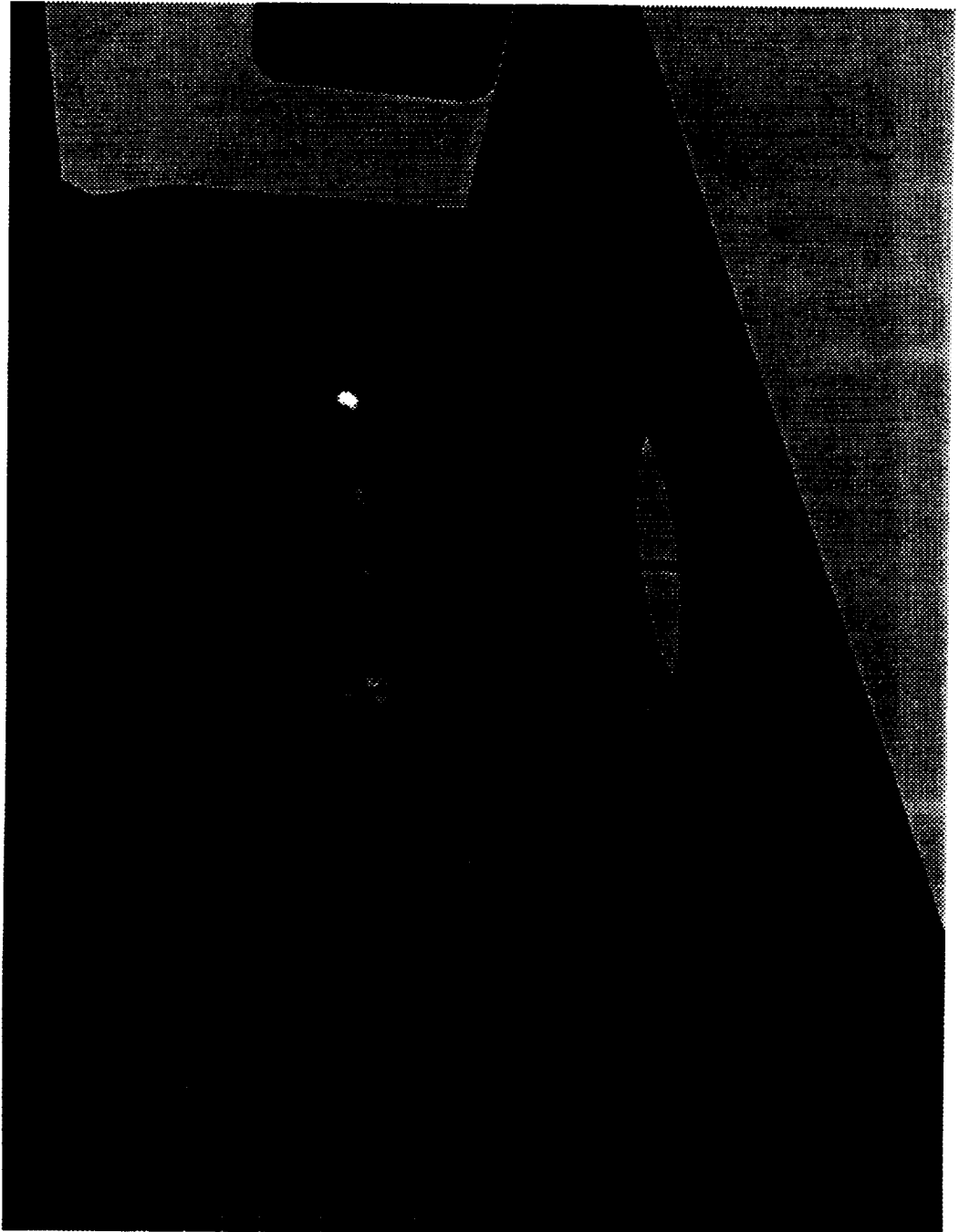
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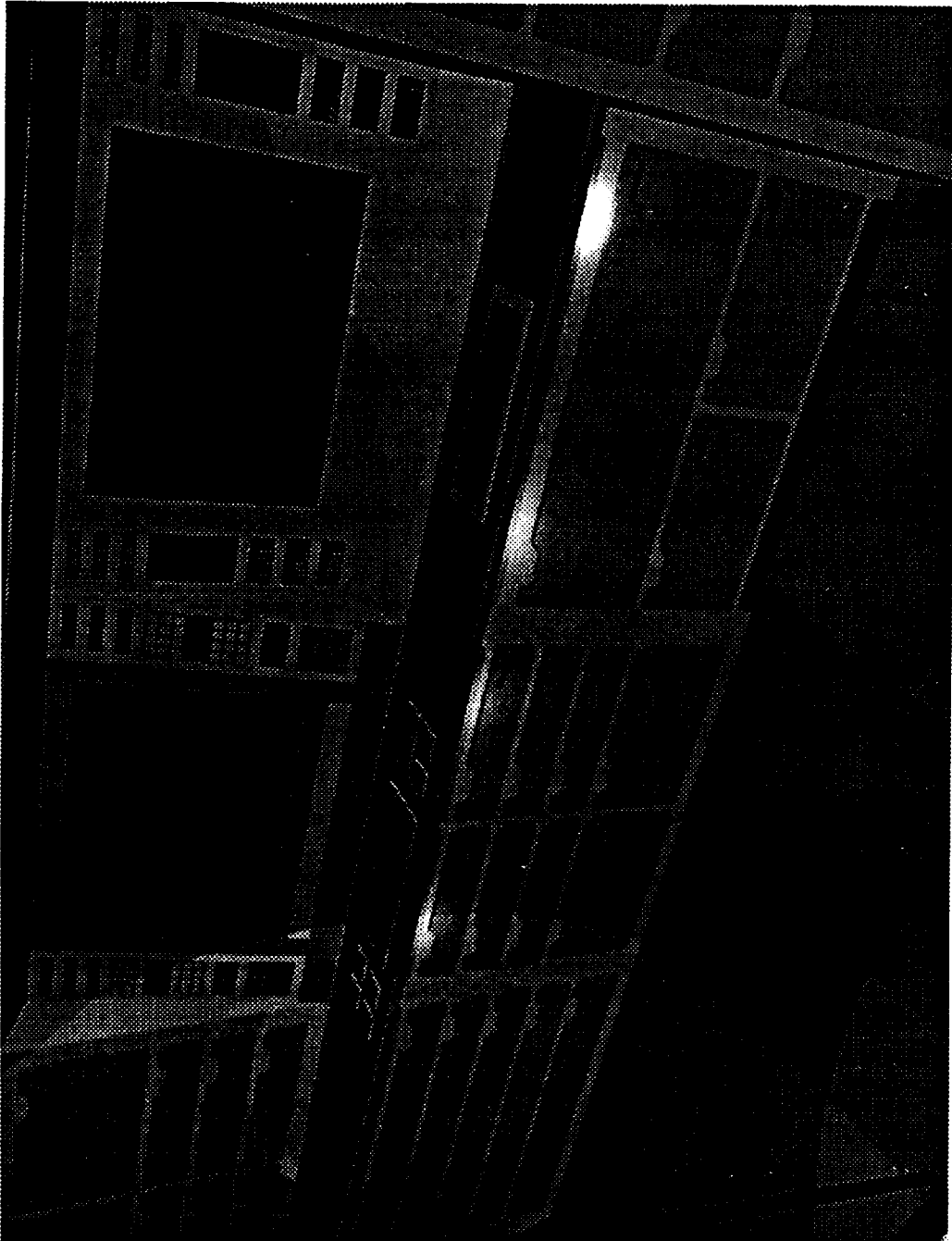
**Section 8**

**Habitat Configuration A**



Section 8

Habitat Configuration A



## Section 9 Habitat Configuration B

### 9.1 Architecture

#### Design strategies

The analytical studies (section 10) reveals the importance and impact of several functions on the mission itself. It appeared at a present step of the study that two main drivers based on the First Lunar Outpost Requirements and Guidelines (FLORG) limit the overall space architecture design. Therefore the space architecture design strategy takes into account pre launch, launch, and post launch conditions oriented through volumetric, weight, mission and operating cost issues.

#### Configuration

Under the limits based on FLORG and analytical studies, the overall space architecture design is influenced directly by airlock and crew quarters concepts. The configuration selected for the airlock is an equipment lock included in the habitat module and an independant crew lock for two astronauts. Crew quarters and storm shelter above deck is the configuration selected and follows the analytical study recommendation (section 10).

### 9.2 Crew Quarters

The crew quarters will provide for activities operating under the architecture strategy (section 9.1) and the lunar partial gravity requirements. The volume allocated will address space for turning, head sitting and knee room.

Crew quarters will have to provide a relative to an outpost mission, privacy, personal storage and recreation facilities.

Crew quarters must address reconfiguration modes, individual ingress and egress, and circulation. Also, the crew quarters configuration may facilitate dust management and cleaning.

#### Configuration

The crew quarters configuration is the result of a deep study that evaluated solar, cosmic radiation protection, volumetric and weight requirements. The suggested above deck configuration allows an optimization of weight, rack utilization, privacy while providing for personal activity. Storm shelter, crew quarters and personal recreation combination is the design proposed.

The crew quarters concept clusters individual access hatch, sleeping (and relative to seven days average solar events,) personal recreation areas. Direct access to the crew quarters is given by an individual deployable ladder. This allows during nominal mission operations individual access and egress as required and doesn't need modification during an exceptional mission event. Each crew quarter is provided with a variable geometry recliner, workstation, a part of personal storage and storm shelter consumables. (to reduce the storm shelter mass). An anthropomorphic and ergonomic design is address to inside sitting and sleeping postures. Crew quarters will enclose personal communication, video, audio, computing and recreational functions.

## Section 9 Habitat Configuration B

### 9.3 Storm Shelter

#### Strategies

The combination of crew quarters and storm shelter must be optimal and has a priority in the concept of a first lunar outpost design because it involves in the same time safety of astronauts, the mass involved and the volume associated with this function. In other words, the feasibility of the mission. The issues are (in order of importance); radiation protection, volume, and weight requirements. To perform and master this critical function, basic measures and quantities; weight (section 10.4), radiation protection (section 10.2), water (section 10.3) have been under control and are closely followed.

#### Configuration

The storm shelter envelopes the crew quarters. Solar and cosmic radiation protection is provided through the implementation of a water bladder and lead panels. The water bladder will allow H<sub>2</sub>O molecule recombination (back reaction) distillate or de-mineralized water for several missions.

The storm shelter-water bladder demineralization demand, slow recirculation, and reuse of water requirements (analysis section 10.2) impose a closed loop system and constitutes the mission H<sub>2</sub>O base calculation.

The storm shelter dimensions for a shielding level of 20 G/CM<sup>2</sup> use 6 CM of AL in conjunction with 4 CM of water.

#### Storm Shelter Dimensions

	G/CM <sup>3</sup>	Thickness for 20 G/CM <sup>2</sup>	G/CM <sup>2</sup>	16 G/CM <sup>2</sup>	4 G/CM <sup>2</sup>
Aluminum	2.65 G/CM <sup>3</sup>	7.5 CM	0.37 CM	6 CM	
Water	1.00 G/CM <sup>3</sup>	20 CM	1.00 CM		4 CM
<b>TOTAL</b>			<b>20 G/CM<sup>2</sup></b>	<b>10 CM</b>	

The storm shelter environment and life support system will be operational within an average solar flare event of seven days (section 10.2 ref. 5). In consequence, it will provide consumables, waste management facilities, body cleaning and health maintenance for this period.

A reduced operation mode during solar flare event will allow a limited number of activities. In fact each crew quarter is provided with a lead glass window and computing system. The presence of a window will allow a direct visual control on the main workstation and science area. The computing system interfaced with a few scientific experiments and a communication workstation will allow the performance of a number of operations from an individual workstation.

## Section 9                      Habitat Configuration B

A window may extend virtually the shelter envelope and may play a positive psychological role in particular events. Lead glass at each individual access hatch may also provide adequate radiation protection.

The ceiling storm shelter configuration not only optimizes radiation protection, weight and volume, but also may anticipate budgetary or weight reduction demand with a minimum impact on the overall architecture. Manned space missions are testimonies of the impact on the living areas. An anticipated solution that could reduce mass is a deployable crew quarter envelope at both extremities. Sliding partitions may partially move through a central storm shelter during solar storm contingency operations.

### 9.4        EVA Systems

#### Strategies

The airlock is one of the two main drivers (section 9.1) in the FLO architecture. A deep analytical study (section 10.1-10.2) is applied to optimize the critical aspects of this function. Time reduction, mass penalty, safety, load reaction, volume, operation cost are optimized following the FLORG and the analytical studies.

#### Configuration

The equipment lock (EL), in consequence of the analytical study and following FLORG determines to be dependent on the habitat module, and the external crew lock independent of the habitat structure. The crew lock (CL) configuration for two crew members at one time (by its small volume) may reduce depressurization time requirements, operating costs, and optimize emergency operations. The gas volume of the crew lock may be pumped into the habitat module, reducing the pump system requirements, and at the same time contribute to reduce the mission cost.

By the use of a high pressure rigid space suit, the risk of decompression sickness (DCS) is minimal. A portable hyperbaric system may be optional for the first missions. Further hyperbaric treatment may be accommodated within the CL envelope after the system installation.

The equipment lock is separated from the habitat module by dust shielding to enclose EMU, a dedicated suit donning area, and SPCU for two astronauts at one time. Temporary stowage of scientific samples may find accommodation in the equipment lock prior to transfer to investigation in the FLO scientific laboratory. The EL may also use the habitat utility systems and structure.

## Section 9                      Habitat Configuration B

### 9.5        Science/Operations Workstation

The science/operations workstation may provide computing, communication facilities, and may support robotics operations. To a communication and computational system, a window may add EVA and robotics direct operation control.

The science/operation workstation involves data collection, updating and maintenance programs, and may produce a flexible and modular environment to satisfy different operational modes.

### 9.6        Science/Laboratory

The large science area is designed to perform scientific activities within a period of 45 days. A component modularity should satisfy a rack reconfiguration in order to receive new equipment and perform different experiments.

A more detailed design configuration requires further studies but a range of basic lunar experimental investigations allow a basic scientific laboratory to be configured in order to perform, biological, life science, materials and partial gravity experiments.

The science configuration contains two science glove boxes, monitoring systems, storage, maintenance area, and experimental hardware.

An above deck area may be the support of long duration experiments and may provide body restraint facilities to perform experimental maintenance and control. The scientific area may also allow the following basic scientific activities: photography, astronomy, geology, chemical analysis.

### 9.7        Recreation area

This area is constituted of a combination of personal recreation and scientific observation.

Since the crew quarters/storm shelter is designed for a mass optimization, to perform the combination of the above two activities, a supplementary recreation area may provide a separated quiet envelope.

A window may permit this activity to support Earth and astronomy observations and photography.

The variable geometry recliner provides for sitting configurations under ergonomic and anthropomorphic design considerations. A workstation system provided for personal communication, video, audio, computing and recreational functions.

The use of this area can answer the demand of privacy or the need to evolve openly in contact with other crew members.

## **Section 9                      Habitat Configuration B**

### **9.8        Circulation**

A deployable ladder may allow an individual access hatch to the crew quarters and support a partial gravity circulation mode.

### **9.9        Utilities**

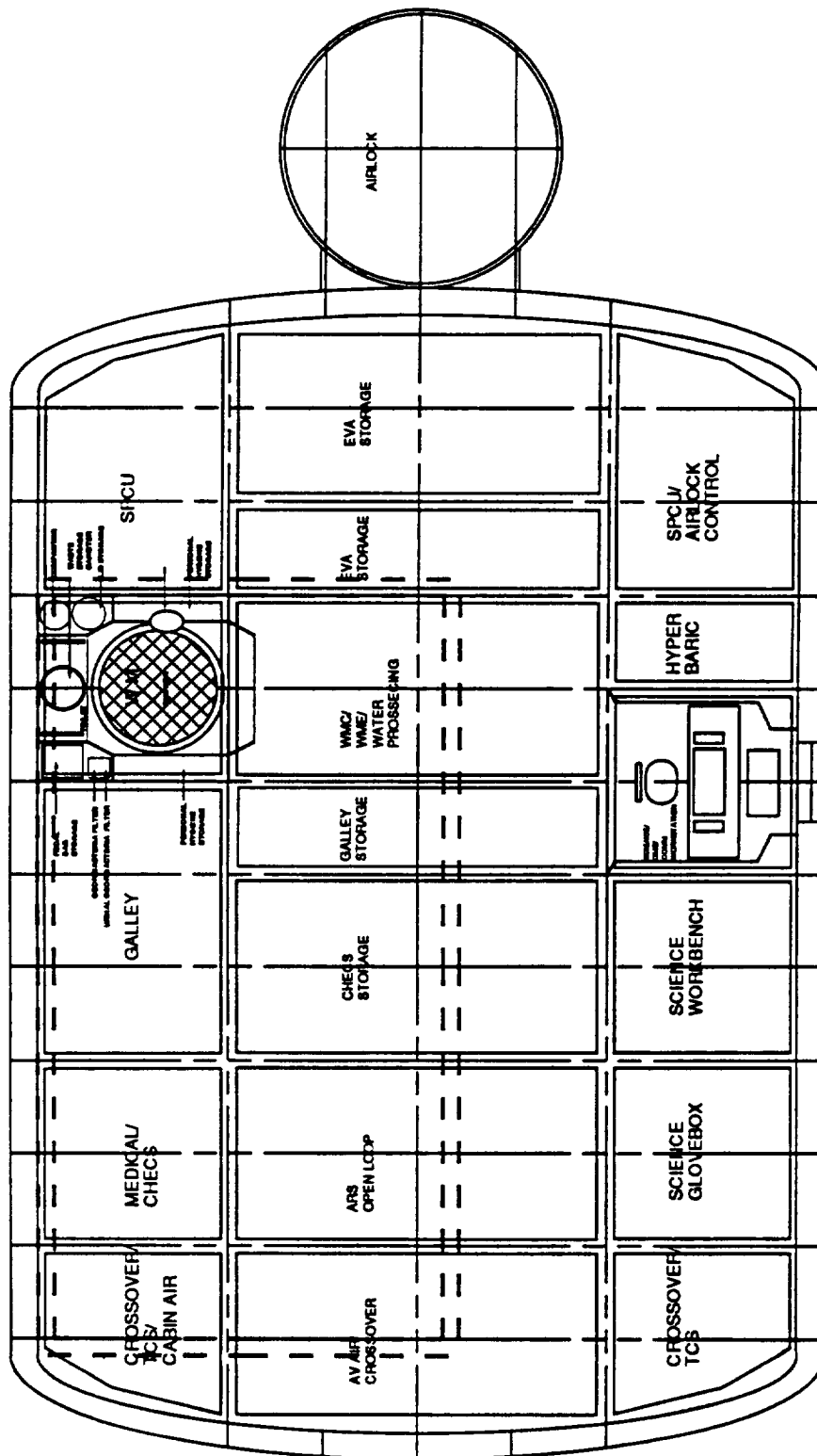
The fluid, gas, and electrical power systems are separated and provide an optimum safety by being separated. This configuration takes advantage of SSF utilities safety concepts.

The rack configuration may also provide easy access to both utilities groups. The volume allocated to fluid and gas supply may satisfy noise standards.



Section 9

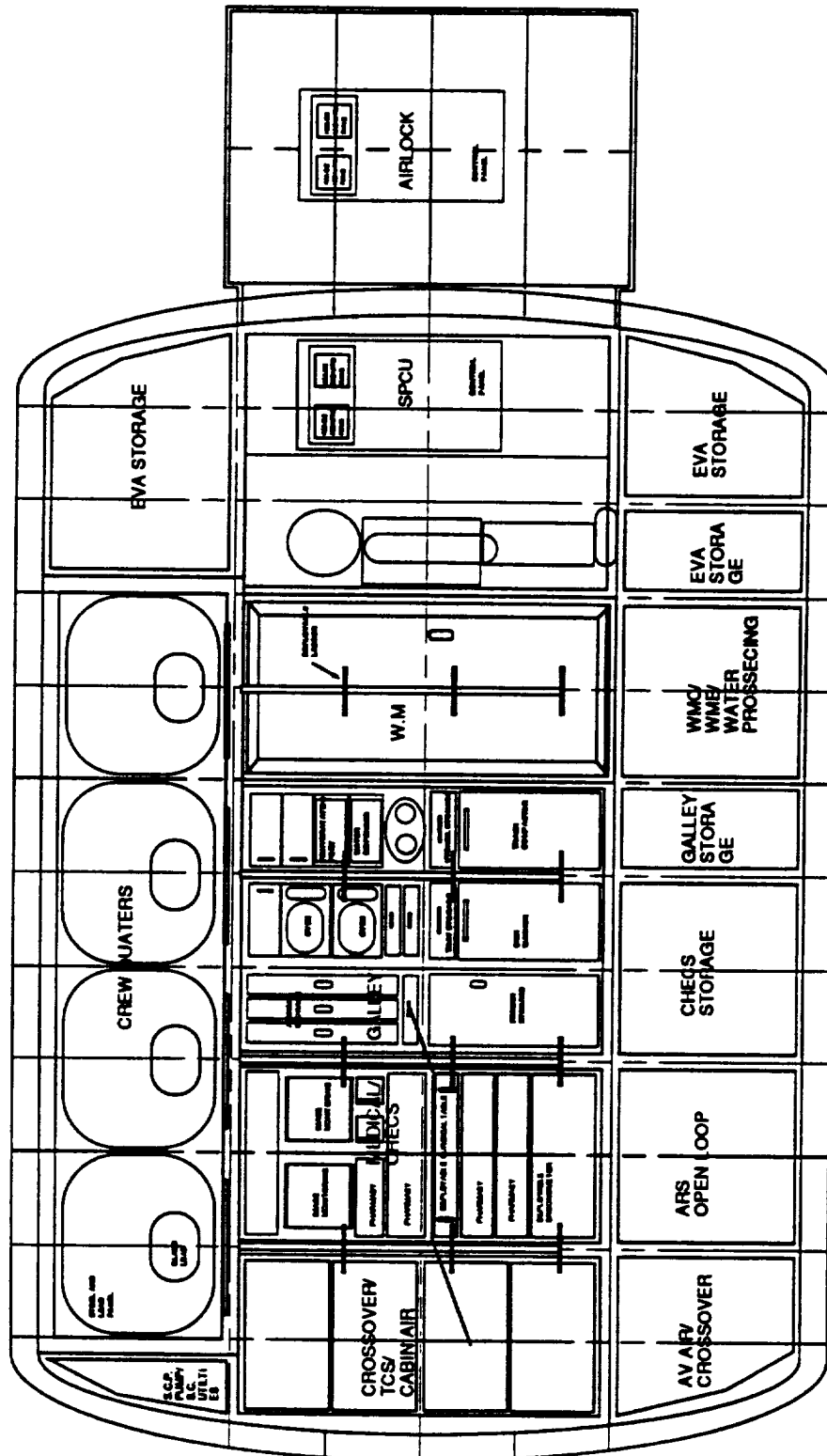
Habitat Configuration B



PLAN 1A

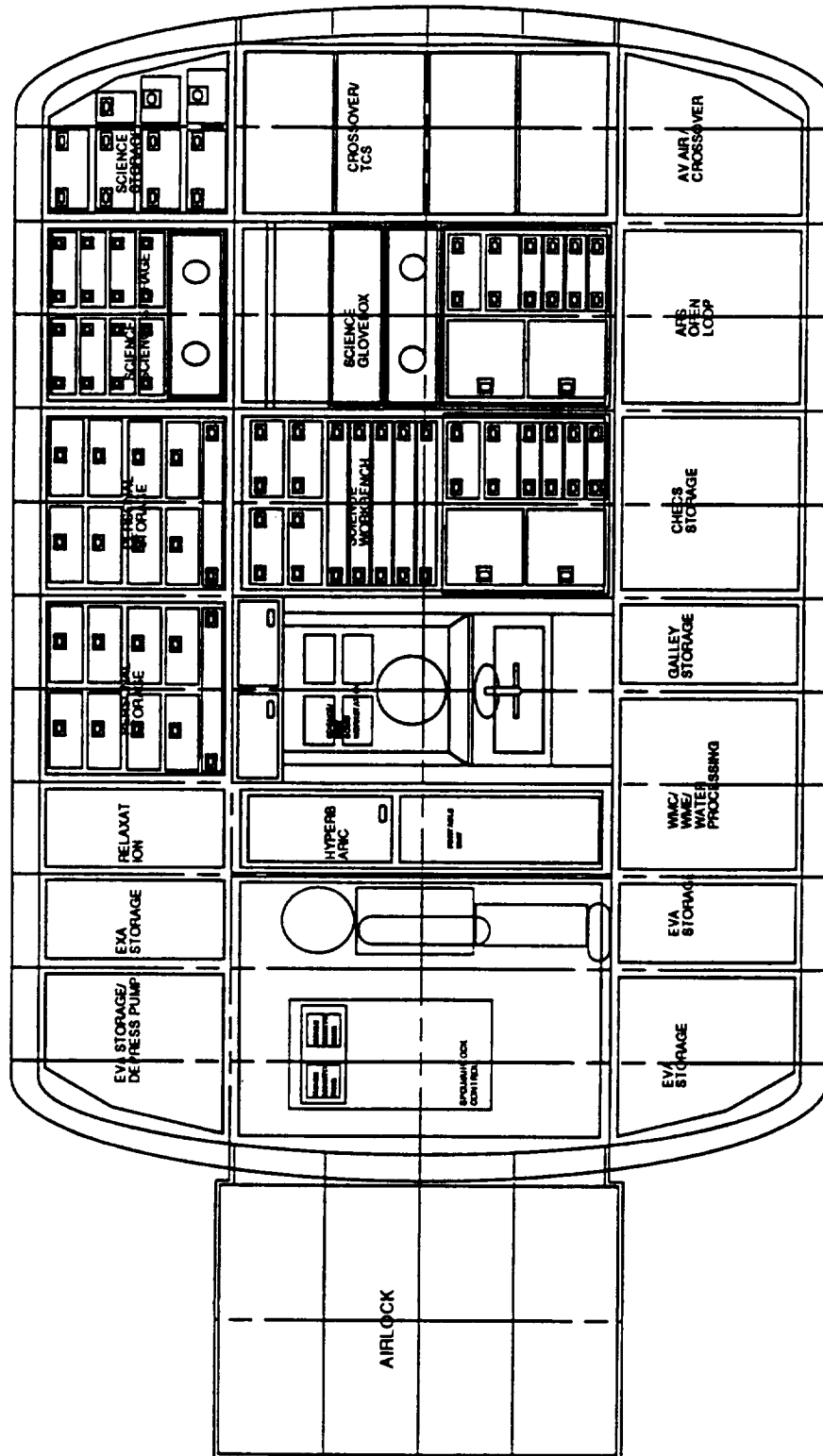
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Habitat Configuration B



ELEVATION 1A

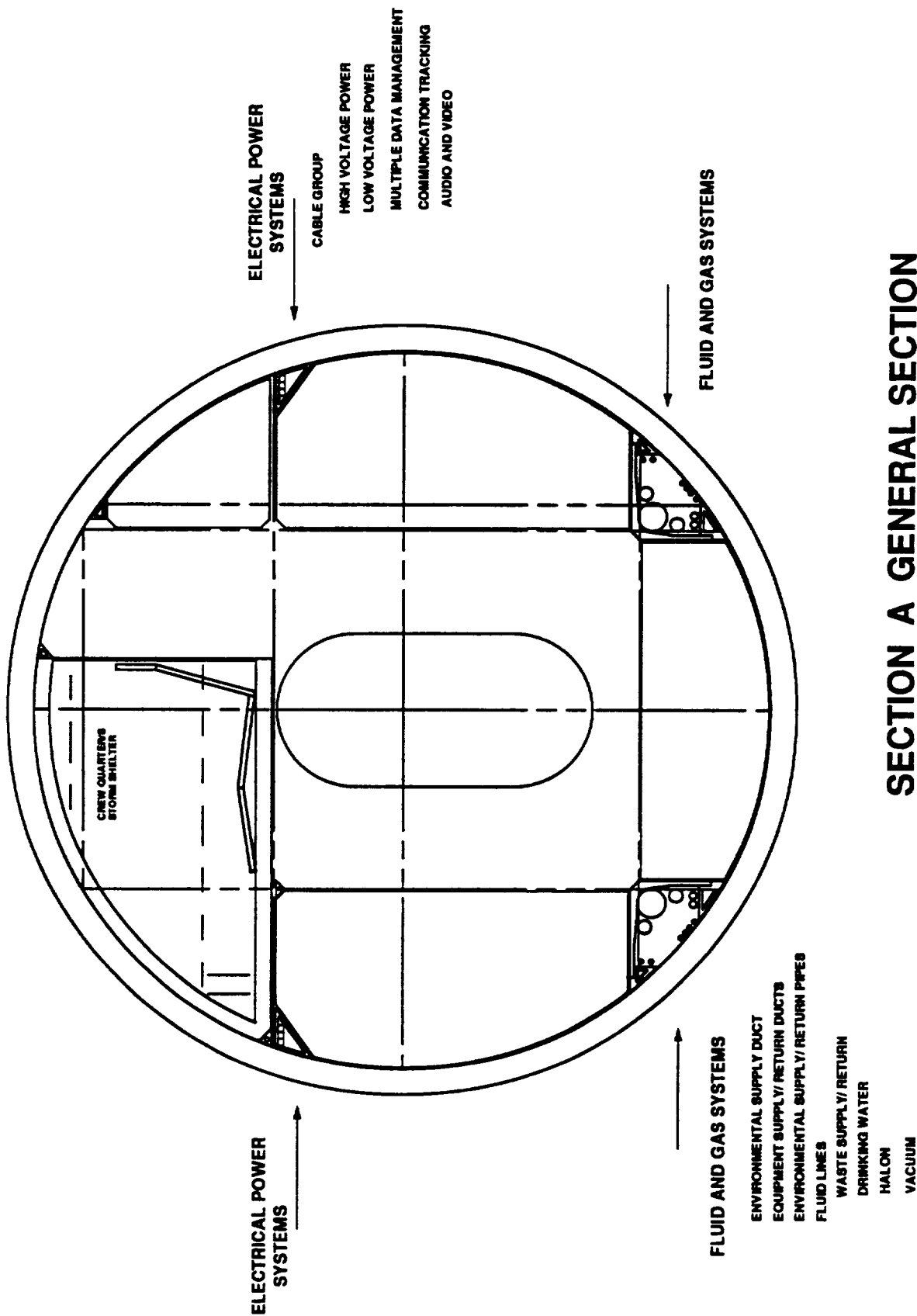
## Section 9 Habitat Configuration B



## ELEVATION 2A

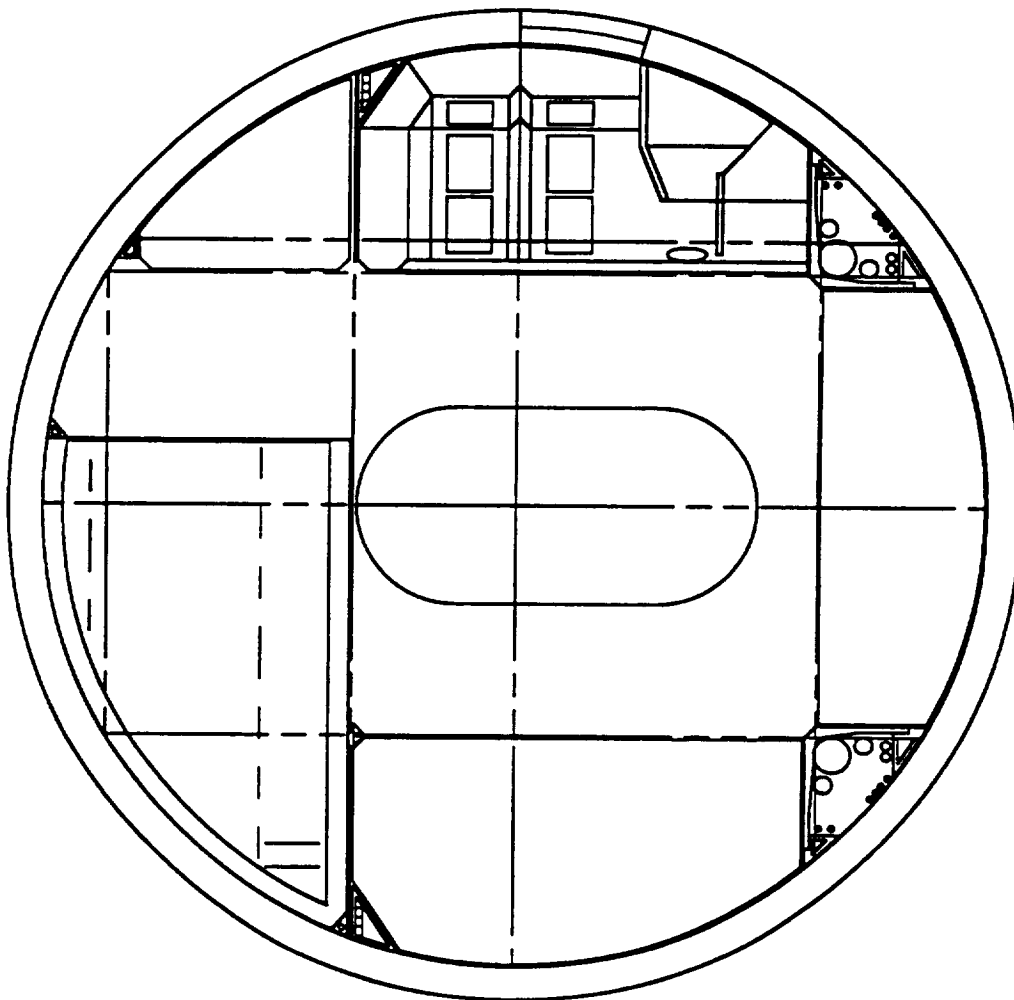
Section 9

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Section 9

Habitat Configuration B



SECTION C

## Section 10 Analytical Studies

### 10.1 EVA Systems Analysis

#### Objectives

The basic EVA system objectives are to allow work outside the habitat, to facilitate equipment transfer, and to provide a lunar dust control system.

#### EVA Systems Components <sup>12</sup>

- Crew lock
- EMU servicing, maintenance, and recharge station
- EMUs
- A full complement of EVA tools and equipment
- A modular EVA tool caddy
- Equipment lock
- A modular EMU consumable augmentation kit for use on the Rover support of extended EVAs
- EVA system spare parts
- External and internal Lunar dust control and removal equipment

#### Preliminary concepts for FLO

##### Airlock Design

The airlock is a driver in the module concept. Its design depends upon hyperbaric requirements and associated needs, the size of LRU ( Lunar Replaceable unit ) to be passed through the airlock, the number of crewmembers to be cycled through at one time, and the hatch and interior dimensions necessary to allow crew members to pass through the airlock.

##### Hyperbaric Operations

The hyperbaric operations influence both airlock and habitation. The airlock structure depends upon the internal pressure. The recommended hyperbaric pressure is 2.8 ATM and SSF requirements for hyperbaric operations are as follows, (1) the patient is to be horizontal and attended by a crew medical officer who has access to all sides of the patient, (2) hyperbaric control equipment and medical equipment are required to monitor, diagnose, and respond to the patients' condition. <sup>13</sup>

Some other basic airlock requirements drive the internal volume needs. The airlock volumes leads to estimation of the gas quantities, the size of depressurization pump system, power requirements, and the operational procedures.

## Section 10 Analytical Studies

### Space Suit Assumption: Rigid High Pressure Space Suit

#### Advantages

This type of suit can provide frequent EVA support while lessening the risk of D.C.S..<sup>14</sup> A high pressure suit of 55.2 KN/M<sup>2</sup> TO 57.2 KN/M<sup>2</sup>(8 PSIA to 8.3 PSIA) reduces the need for prebreathing and also allows the use of a gas mixture rather than 100% oxygen.<sup>15, 16</sup>

The EVA crew member may experience fatigue due to the energy required to overcome the springback characteristics of fabric suits (which require more energy for operations than rigid suits ).

Radiation and micro-meteorite protection is superior in a rigid suit .

#### Characteristics

##### Operating Pressure :

The operating pressure is 57.2 KN/M<sup>2</sup> ( 8.3 PSIA) and 29.7 KN/M<sup>2</sup> is the lower pressure for the current issue American space suit.<sup>17</sup> The first advantage is that it reduces or eliminates the need for prebreathe. Prebreathing is reduced or eliminated because the possibility of nitrogen bubble formation is reduced to a minimum in a 57.2 KN/M<sup>2</sup> (8.3 PSIA) suit. The second advantage is that it eliminates the need to lower the planetary base pressure in preparation for an EVA using a high pressure space suit. Altering the planetary base pressure is not desirable because laboratory experiments will be disturbed, and more importantly, the cost will be prohibitive.

##### Suit Lifetime:

The cycle testing of metal space suit components reveal a 20-year lifetime for properly maintained bearings and an indefinite lifetime for suit components the shuttle EMU space suit components are inspected after every five EVAs and have a life cycle of 8 years.

## Section 10 Analytical Studies

### Maintenance and cleaning:

Easy to wipe and rinse, a rigid space suit may prove to be of significant cost reduction to the entire program. The current protocol for a space shuttle suit returning from a mission entails 1500 person-hours of seam inspection ,pressure leak checks and backpack life support system refurbishment.

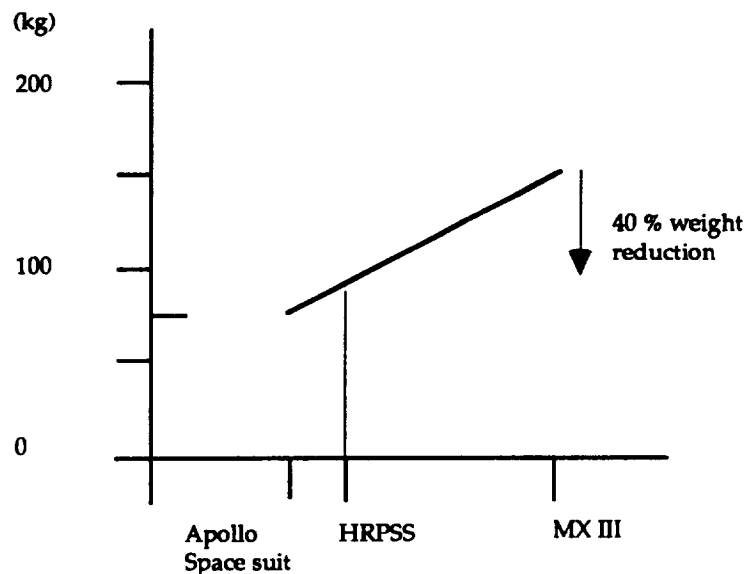
### Disadvantages

The current state of development has to be considered. A high pressure rigid spacesuit design for a lunar EVA must be fully developed and will certainly have a substantial development cost. Manual dexterity and body motion flexibility may be reduced. The efficient joint motion and mobility issues must be addressed. The present design stowability of rigid suits will likely require additional space stowage , and may be only partially deployable.

Finally, the current rigid suit research has developed suit types of substantial weight, which may prove excessive in the lunar environment.

### Assumptions

A high pressure rigid space suit can be developed in the time frame of current lunar mission planning. It will be desirable to pursue rigid suit development in conjunction with lunar mission planning, for lunar and planetary utilization. A staged permanent lunar presence is a future goal of lunar planning, and current studies should address issues of expandability and reutilization.



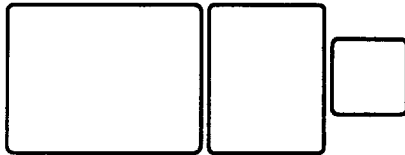
HRPSS ( High Pressure Rigid Space Suit )



## Section 10 Analytical Studies

### Preliminary Airlock Concept Comparison

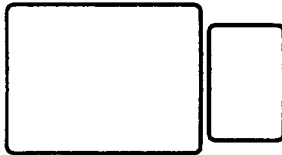
#### Solution A



FLO 92 UH

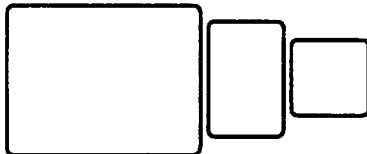
- EL for 4
- Deployable CL
- Hab and airlock vol disproportionate
- EL vol -> increases weight  
-> ssf layout
- Three different structures (Load-reaction). Structurally complex
- ADV -> dust management  
-> stowage

#### Solution B



- Allows airlock/eva equipment to be located in the airlock.
- Addition of separate structure element
- Increases gas loss
- Must be designed for 4 crew members
- May be lighter than FLO 92
- The depress time may be longer

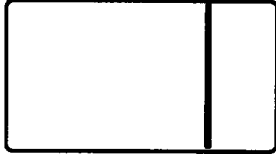
#### Solution C



- Addition of separate structure element. Structurally complex
- Doesn't exploit HRPSS (high rigid pressure space suit) capabilities.
- Imposes a minimum airlock design for 4
- Better for gas loss

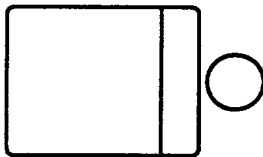
## Section 10 Analytical Studies

### Solution D<sup>18</sup>



- Allows airlock/EVA equipment to be located in the airlock . may improve dust management.
- Eliminates addition of separate structure element.
- Internal bulkhead attached at existing girth ring provides structural mass.
- Doesn't exploit HRPSS capabilities
- Imposes a minimum design for 4
- Increases gas loss

### Solution E



- Provides a minimum vol airlock, reducing depress power requirement.
- Adequate size for two suited astronauts, vertical orientation.
- Airlock/EVA suit support equipment located in hab
- Reduces gas loss
- Exploites HRPSS capabilities
- CL can be design for 1 or 2 crew members-> allows aFLO minimum approach design.

## Section 10 Analytical Studies

Operation Cost (Comparison between SolutionB and Solution E) : 19

## Solution B

- Volume ( $\pi D^2 H / 4$ )  $= \pi \times 132^2 \times 67 / 4$   
 $= 530.6 \text{ FT}^3$
- Volume to be pumped  $= 530.6 - 155.2$   
(gas : 380 g /  $\text{FT}^3$ )  $= 375.4 \text{ ft}^3$   
 $= 14,265.2 \text{ g of gas}$
- Assumption : with 10% loss / EVA (NASA SSF)  $= 1,426.52 \text{ G}$
- With 28 EVA  $= \underline{39,942 \text{ g}}$

## Solution E

- Volume ( $\pi D^2 H / 4$ )  $= \pi \times 60.4^2 \times 88 / 4$   
 $= 146 \text{ FT}^3$
- Total vol. to be pumped  $= 146 - 77.6$   
 $= 68.4 \text{ FT}^3$
- Volume gas  $= 2,599.2 \text{ g}$
- Assumption : with 10% loss/ EVA (NASA SSF)  $= 259.92 \text{ g}$
- 28 EVA  $= \underline{7,277 \text{ g}}$
- Difference Between B and E  $= 32 \text{ KG +STRUCTURE}$
- Weight penalty / mission  $= 62 \text{ kg}$   
 $(\$ 93,000/\text{mission})$

## Overall

- Solution E  $= 0.25 \text{ kg/use}$
- Solution X  $= 0.60 \text{ kg/use(SSF)}$
- Solution B  $= 1.42 \text{ kg / use}$

Preliminary Airlock Concept Conclusion

The need to conserve air and energy resources requires an airlock design that will minimize the amount of air lost each time it is used. To minimize this air loss, a 2 man minimum airlock appears to be the best solution. Also in order to reduce the missions cost, the airlock air volume could be pumped into the hab module.

## Section 10                      Analytical Studies

### EVA Systems: Airlock Design <sup>20</sup>

#### Design Criteria

The general design criteria which must be met by all proposed alternatives are as follows:

- The airlock must minimize the loss of air when it is used
- The airlock must be big enough for 2 fully equipped crew members with some small tools to pass through comfortably. <sup>21</sup>
- The airlock must be strong enough to withstand repeated pressurization at 2.8 ATM pressure .
- The airlock must have built-in safety features for emergencies.
- The airlock must have instruments to indicate conditions inside the airlock.
- The conditions in the airlock must be monitored within the hab module.
- The airlock must have a minimal weight to minimize transportation costs and hab module design.

Component (overall view):

- overall configuration
- sealing system
- vacuum pump system
- measurements and instrumentation
- material selection
- hyperbaric treatment systems and requirements

## Section 10 Analytical Studies

Cylindrical airlock air evacuation time calculation using a Sciding vane pump.

$$T = 6.5 V/S \text{ (LTynold vacuum handbook)}$$

$$V = \text{Total airlock volume to be pumped. (cu ft)}$$

$$S = \text{Pump displacement rate( with a sliding vacuum pump)}$$

$$= 494 \text{ cu ft / min. } \rightarrow (\text{kinney vacuum pump})$$

Total volume of the airlock to be pumped out  
= vol. of cyl airlock - vol. of 2 astronaut space suits

### Volume of the space suit

ref : standard dimensions of a space suit

- Life support system 2.98 cu ft
- Vol. of two legs 4.58 cu ft
- Vol. of two arms 0.98 cu ft
- Vol. of torso 10.90 cu ft

Total for one suit 19.40 cu ft  
Total for two suits 38.80 cu ft

### Volume of cylindrical airlock ( $V = \pi D^2 H/4$ )

$$\text{Vol. airlock} = \pi \times 60.4^2 \times 88 / 4$$

$$= 145.9 \text{ cu ft}$$

$$\text{Total volume to be pumped} = 145.9 \text{ cu ft} - 77.6 \text{ cu ft}$$

$$= 68.4 \text{ cu ft}$$

$$\text{Pump down time} = 6.5 \times V / S$$

$$= 6.5 \times 68.4 \text{ cu ft} / (494 \text{ cu ft/ min.})$$

$$= 0.9 \text{ min. or 54 sec}$$

### Percentage of air recovery

#### Assumption

- initial pressure 0.69 ATM
- final pressure 0.00069 ATM

P = Airlock pressure  
R = Universal gas constant  
T = Temperature

## Section 10 Analytical Studies

$$\begin{aligned}M &= \text{Total mass air} \\V &= \text{Volume airlock} \\&= \text{Original air mass} - \text{final air mass} / \text{original air mass} \\&= M_1 - M_2 / M_1 \\&= (P_1 / R_1 T_1 V_1) - (P_2 / R_2 T_2 V_2) / (P_1 / R_1 T_1 V_1) \\&= P_1 - P_2 / P_1 \\&= 0.99\end{aligned}$$

Analysis of the weight of outer wall

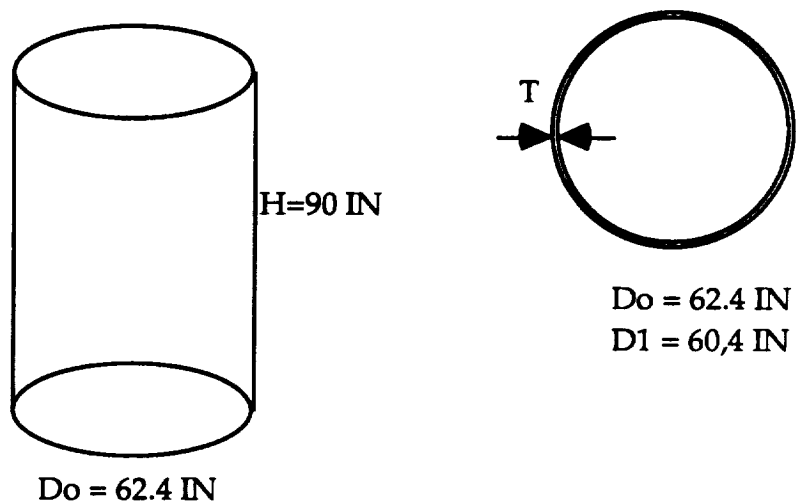
Assumption:

1. cylindrical as a thin wall hollow cylindrical vessel
2. maximum pressure,  $P_{\max.} = 56\text{psi}$
3. factor of safety = 8

Properties:

- aluminum
- density,  $\rho = 0.096\text{ LB / CU IN}$
- ultimate tensile strength,  $UTS = 198 \times 10^3\text{ PSI}$

Schematic:



Section 10 Analytical Studies

Analysis : Analysis of the weight of airlock outer wall

Using Hooks law for thin walled vessels

$$\begin{aligned} T &= NP_{\max} D / 2UTS \\ &= 8 \times 56 \text{ PSI} \times 62.4 \text{ IN} / 2 \times 198 \times 10^3 \text{ PSI} \\ &= 0.07 \text{ in} \quad \leftarrow \text{Wall thickness} \end{aligned}$$

Volume of the material

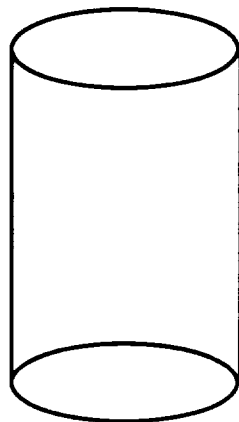
$$\begin{aligned} &= [\pi D_0^2 H / 4 - \pi (D_0 - T)^2 (H - T) / 4] + [\pi D_0^2 T / 4] \\ &= [\pi 62.4^2 90 / 4 - \pi (62.4 - 0.07)^2 (90 - 0.07) / 4] + \pi \\ &\quad \quad \quad 62.4^2 \times 0.07 / 2 \\ &= 1258.7 \text{ IN}^3 \end{aligned}$$

Weight of the outer wall

$$\begin{aligned} &= 1258.7 \text{ in}^3 \times (0.096 \text{ LB/in}^3) \\ &= 120.8 \text{ LB} \end{aligned}$$

Analysis of the weight of airlock inner wall

Schematic:



$$H = 88 \text{ IN}$$

$$D1 = 60.4 \text{ IN}$$

## Section 10 Analytical Studies

Thickness:

$$P_{\max.} = 56 \text{ PSI}$$

$$T = \frac{8 \times 56 \times 60.4 \text{ IN}}{2 \times 198 \times 10^3 \text{ PSI}} = 0.07 \text{ IN}$$

Volume :

$$\begin{aligned} &= [\pi (D_1 + T)^2 (H + T) / 4] - [\pi (D_1)^2 H / 4] + [\pi D^2 T / 2] \\ &= [\pi (60.4 + 0.07)^2 (88 + 0.07) / 4] - [\pi (60.4)^2 88 / 4] + [\pi (60.4)^2 (0.07) / 2] \end{aligned}$$

$$= 1,186.9 \text{ IN}^3$$

Weight :

$$= 1,186.9 \times 0.096 = 113.9 \text{ LB}$$

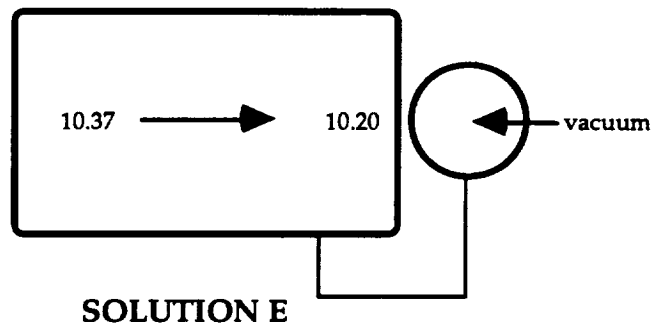
Total weight

$$\begin{aligned} &= 120.8 + 113.9 \\ &= 234.7 \text{ LB ( 270.3 KG)} \end{aligned}$$

### Habitat Module Pressure Analysis conclusion

- Vol. air HAB mod = 3885 ft<sup>3</sup> → P = 10.2
- Vol. air airlock = 68.4 ft<sup>3</sup> → P = 10.2
- Vol. air hab module + Vol. air airlock = 3885 ft<sup>3</sup> + 68.4 ft<sup>3</sup> = 3953.4 ft<sup>3</sup>

P airlock = 0 ==> 10.2 to 10.37 PSI





## Section 10 Analytical Studies

### Section 10.2 Radiation Protection Storm Shelter

#### Radiation Environment <sup>22</sup>

##### Galactic Cosmic Radiation ( GCR )

- Cosmic rays
  - Energies  $E = 10 \text{ MeV to } 100 \text{ GeV}$
  - Charges  $Z = 1 \text{ to } Z = 30$
  - Ignored
    - Low energy charged particles
    - Rare ultra heavy cosmic rays  $Z > 30$
- Composition
  - Protons
  - Helium Nuclei (alphas)
  - 1 % heavy ions
    - Carbon
    - Iron nuclei. [ 4 times radiation of proton] and RBE (Relative biological effectiveness)
- Characteristics
  - continuous source of highly penetrating particles
- Predictions
  - GCR at solar minimum : Years 1996 - 2007 - 2018
  - GCR at solar maximum : Years 2002 - 2013 - 2024

##### Solar Energetic Particles (SEP)

- Composition
  - Protons
- Characteristics
  - Intermittent
  - Intense (proton fluxes)
  - Correlated with sun spot activity
- Predictions
  - August, 1972 Solar energetic particle event: every 10 to 20 years
  - Composite worst case solar flare 1956: once every century

## Section 10                      Analytical Studies

### Radiation Protection

#### Galactic Cosmic Radiation

- At solar minimum

The expected dose from Galactic cosmic radiation at solar minimum with no shielding is 49 REM/ year.

This is within the proposed NCRP annual limits

- At solar maximum

During solar maximum the GCR dose equivalent is less than 20 REM/year for all shielding thicknesses.

No shielding against GCR radiation is required to meet the proposed NCRP annual dose limit during solar maximum.

A three years space flight to Mars at solar minimum will result in an absorbed dose of about 100 REM with the shielding thicknesses recommended (20 REM/YEAR). <sup>23</sup>

The 50 annual dose limit for astronauts exceed terrestrial limits for general population by 100 times. 50 REM is approximately the dose from GCR in free space at solar minimum. On the lunar surface the dose is about 30 REM/year.

## Section 10 Analytical Studies

Solar Flare Storm Shelter

There is one chance in 500 of astronaut death and mission failure because of solar flares for each week without shielding outside Earth's magnetosphere

$$2 \times 7 / 20 \times 360$$

" 2 / 20" : This number is base on the fact that lethal particle fluxes from the sun are present for 2 days in each 20 year period. This was based on the August, 1972 flare . It was the most intense flare ever observed. The effective duration of August, 1972 flare at peak intensity is 15.5 hours.

- A minimum of  $20 \text{ g/cm}^2$  (7.5 cm ) Aluminum shielding ( or equivalent effect) IN ALL DIRECTIONS is required for the storm shelter. <sup>24</sup>
- This amount of shielding reduces the dose associated with the August, 1972 Solar flare to a survivable 40 REM → 2.58 REM/ HOUR during 15.5 HOURS = 40 REM
- A storm shelter for more massive than recommended above would be needed to shield against the composite worst flare. <sup>25</sup> In fact the exposure to protons at the composite worst case flare intensity ( once a century ) for a period of 16 hours would result in an absorbed dose of more than 240 REM even with  $70 \text{ g/cm}^2$  (26 cm) Aluminum shielding. At this intensity it must be assumed that most astronauts would be die from exposure and that the mission would be aborted. <sup>26</sup>

## Section 10 Analytical Studies

### 10.3 ECLSS Analysis

#### Synthesis

##### Total resupply

Open loop → 5,648.40 KG  
Closed loop → 1,063.19 KG

##### Water resupply

Open loop → 4,811.40 KG — 169.84 ft<sup>3</sup>  
Closedloop → 505.19 KG — 17.83 ft<sup>3</sup>

In consequence , if water was a part of the storm shelter structure in a closed loop system, there isn't enough water to provide 20 g/ cm<sup>2</sup> of radiation protection. An open loop system would solve the problem but would have a direct impact on the mission operating cost ( \$ 6,459,315 in addition each mission). <sup>27</sup>

#### The use of water in a shielding system <sup>28</sup>

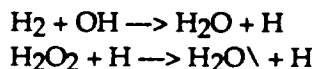
H<sub>2</sub>O is cheap and readily available, nonpoisonous and, for the most part stable. Care should be taken when procuring the water sothat it does not contain dissolved salts that will assist the water decomposition into hydrogen and oxygen gas. For this reason distilled or demineralized water is justified.

Surface and ground waters contain various dissolved salts that can cause gassing of shield water or undesirable deposition of scale in the shield tank. Radiation can cause dissociation of water as a result of the radiation breaking the chemical bonds holding the atoms together. Thus the products will be molecules or ions composed of various combinaisons of hydrogen and oxygen. When water decomposes, the yields will be



The OH and H<sub>2</sub>O<sub>2</sub> result in the evolution of O<sub>2</sub>.

Back- reactions between these products will reduce the amount of gassing. The principal back- reactions are



## Section 10                      Analytical Studies

These back reactions increase with an increase in pressure. The net hydrogen production, namely, the difference between the generation and recombination of hydrogen is reduced by increasing the pressure and decreasing the impurities.

The back up is also influenced by the dynamic properties of water . If the water is circulating rapidly or if steam or other gases are bubbling through it, the decomposition reaction products will be carried off, which will reduce the back-reaction and result in an increasing in the net evolution rate of gas.

Pure degassed water does not evolve appreciable quantities of gas up to radiation intensities. However , the presence of ordinary impurities dissolved in the water will inhibit the back- reaction and may result in gassing.

This analysis indicates that if there is a use of this type of water for drinking, a distillation or demineralization is required (2.58 kg /day/Ind. or 10.32 kg/day/crew) . This also indicates the inevitable use of a closed loop system.

The storm shelter design has to take into account the water resupply reduction. In fact if the amount of water composing the storm shelter was 1,010.38 Kg , this configuration would require a water resupply every two missions. In consequence , the storm shelter design has a direct influence on the mission operating cost ( \$757,785.00 /mission).

The volume (the water requires 2.65 times more thickness than AL by G/CM<sup>2</sup> of protection), the radiation protection and the minimum water requirement constraints will determine the storm shelter design configuration.

## Section 10 Analytical Studies

### 10.4 Schematic Weight Analysis

This Schematic weight analysis compares two different concepts studied in a previous analysis (section 10.1). The configurations selected are, solution B (with crewlock and equipment lock combined, and crew quarters below deck,) and solution E, (crew quarters above deck and airlock designed for two astronauts.)

	SOLUTION E	SOLUTION B
MODULE STRUCTURE		
PRIMARY	2593 KG	2593KG
SECONDARY	1755 KG	1755KG
RACKS	1863 KG	1863KG
STORM SHELTER	<u>259 KG ( 10 % )</u>	<u>259KG (20 % )</u>
STORM SHELTER		
STRUCTURE	<u>509 KG ( 10% )</u>	<u>509KG ( 10 % )</u>
RAD. PROTECTION	<u>5089KG</u>	<u>7800KG</u>
UTILITIES/EQUIP		
EXTERNAL STRUCTURE	1600 KG	1600 KG
LIFE SUPPORT	2177 KG	2177KG
MEDICAL SUPPORT	445 KG	445KG
CREW SYSTEM	1220 KG	1220 KG
CDMS	761.4 KG	761.4 KG
POWER SOURCE	2719 KG	2719KG
HEAT REJECTION SYSTEM	1645 KG	1645 KG
AIRLOCK SYSTEM	(1000 KG)	(3000 KG)
CREW QUARTERS		
DUST SHIELDING OR P. BULKHEAD		
SYSTEMS SUBTOTAL (HABITAT)	<u>23635KG</u>	<u>28346KG</u>
CONTINGENCY	<u>25998KG</u>	<u>31180KG</u>
CONSUMABLES	2300 KG	2300 KG
FUEL CELL REACTANTS	1218 KG	1218 KG
INTERNAL SCIENCE EQUIPMENT	984 KG	984 KG
TOTAL LANDED	30500KG	35682KG

### Conclusion

The total Solution E weight with 10% contingency indicates that this configuration with crew quarters in the ceiling, a two astronaut airlock concept optimizes the First Lunar Outpost weight mission requirement feasibility.

## Section 11 Conclusions

### Comparison Between habitat configuration A and B

The rating system below uses the numerals 0 through 4 to quantify performance, with a rating of 0 meaning poor and 4 meaning excellent.

<u>Section</u>	<u>Criteria</u>	<u>Rating :A/B</u>	
Crew Quarters	Accessibility	3	2
	Volume	664.65	420 FT <sup>3</sup>
	Percentage of overall volume	17 %	10 %
	Appropriateness of design for 1g use	3	2
	Appropriateness of design for 1/6g	2	3
	Radiation protection	4	4
	Weight	1	4
	Maintenance-Dust control	1	4
Physical Hygiene Facility	Accessibility	3	3
	Volume	173.67	173.67
	Percentage of overall volume	4.6	4.6
	Appropriateness of design for 1g use	3	3
	Appropriateness of design for 1/6g	3	3
	Maintenance	3	3
Health Maintenance Facility	Accessibility	3	3
	Volume	173.67	3
	Percentage of overall volume	4.6	4.6
	Appropriateness of design for 1g use	3	3
	Appropriateness of design for 1/6g	3	3
	Maintenance	3	3
Galley	Accessibility	4	4
	Volume	231.56	231.56
	Percentage of overall volume	6.2	6.2
	Appropriateness of design for 1g use	4	4
	Appropriateness of design for 1/6g	4	4
	Maintenance	4	4
Wardroom	Accessibility	4	4
	Volume		
	Percentage of overall volume		
	Appropriateness of design for 1g use	3	3
	Appropriateness of design for 1/6g	4	4
	Maintenance	3	3

## Section 11

## Conclusions

Airlock	Accessibility	3	3
	Volume		
	Percentage of overall volume		
	Appropriateness of design for 1g use	3	
	Appropriateness of design for 1/6g	3	4
	Operating Cost -Gas lost	2	4
	Weight	2	4
Science laboratory	Depress time	4	4
	Volume		345
	Appropriateness of design for 1g use		
	Appropriateness of design for 1/6g		
	Percentage of the overall volume		9 %
	Mainenance		
Direct external view		0	4
Utilities	Safety	2	4
	Accessibility	2	4



## Section 12 Future Research

### 12.1 Supporting Technical Research

Key drivers supporting habitat and surface development and planetary exploration involve life support systems, radiation protection, and extra-vehicular activity support. Further development of these issues is required to evaluate the proposals put forward in this study.

#### Environmental Control and Life Support Systems

Development and analysis of Environmental Control and Life Support Systems, involving options for water and metabolic gases loop closure, and evaluation of mission consumables.

#### Radiation Protection Issues

Development and analysis of radiation protection systems, involving evaluation of the water bladder concept, analysis of water consumption, recycling and filtering systems, partition and baffle systems, structural integrity and launch stability of proposed systems, and analysis of mass shielding of the habitat structure.

#### Extra-vehicular Activity Systems

Evaluation of EVA support systems, involving airlock configuration, EVA systems analysis, EVA equipment evaluation, EVA activities, habitat support of EVA activities, and materials processing procedures.

### 12.2 Design Development

Additional development of design concepts is required for the evaluation of activity areas and operational tasks, 1/6 G ergonomics, and interfunctional transitions. Efficient mission operations in a confined, partial gravity environment are critical to mission and program success.

#### Activity Areas

Activity and task areas to be considered involve workstation and communications operations, health maintenance and exercise, and scientific analysis operations. A detailed study of these operations should follow preliminary investigations.

#### Ergonomics

Further design development should involve ergonomics evaluation of the 1/6 G environment, in the determination of anthropomorphic guidelines and optimal configuration of task areas.

#### Inter functional Relationships

An analysis of activity patterns and inter functional transitions would support configuration planning as well as workstation development. Specific study should be undertaken in sleep patterns, logistics resupply, EVA support and scientific analysis operations.

## **Section 12                      Future Research**

### **12.3      Design Mockup**

Aspects of this design study may be evaluated through a design mockup, allowing detailed analysis of constructive and operational issues. Mockup studies may involve evaluation of structural components, utility distributions, fastening systems and component modularity. A mockup may be developed allowing component functions to be interchanged or reconfigured. This would allow a platform for detailed component design and analysis, as well as capabilities for evaluation of configuration patterns and relationships. Mockup studies may be incorporated into the existing habitat facility developed at SICSA at the University of Houston campus.

### **12.4      Habitability Studies**

Further work is currently being pursued in the development of habitability and simulation studies at SICSA. Research involves ergonomic, physiological and psychological impact evaluation of the space environment, telerobotics application, workstation development, configuration and evaluation of science applications, and viewing and lighting impact evaluation.

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